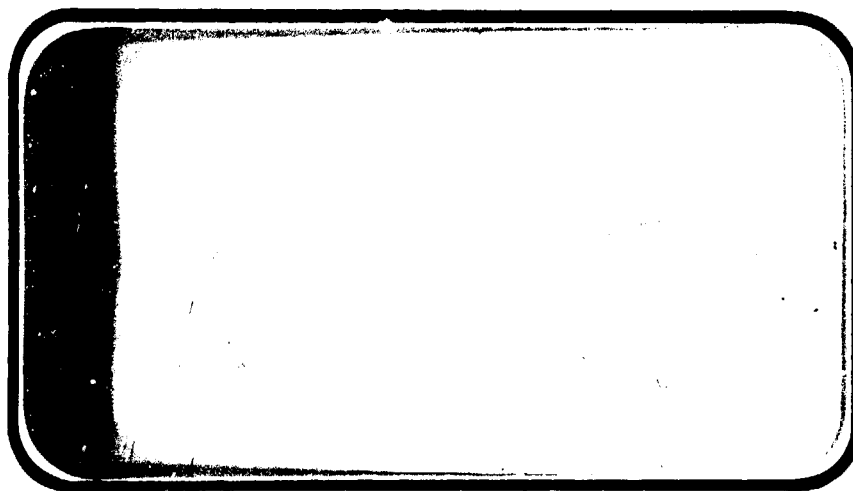




NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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NASA-CR-134087) RESULTS OF FLOW  
VISUALIZATION STUDIES IN THE NASA/MSFC 14  
X 14 INCH TRISONIC WIND TUNNEL ON A  
.004 SCALE MODEL (34-0) SPACE SHUTTLE  
(Chrysler Corp.) 59 p HC \$6.00 CSCL 22B

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SPACE SHUTTLE

AEROTHERMODYNAMIC DATA REPORT

JOHNSON SPACE CENTER  
HOUSTON, TEXAS

DATA MANAGEMENT services

SPACE DIVISION



CHRYSLER  
CORPORATION

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RESULTS OF FLOW VISUALIZATION STUDIES IN THE  
NASA/MSFC 14 x 14 INCH TRISONIC WIND TUNNEL  
ON A .004 SCALE MODEL (34-0) SPACE SHUTTLE ORBITER  
AND INTEGRATED VEHICLE

By

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Prepared under NASA Contract Number NAS9-13247

by

Data Management Services  
Chrysler Corporation Space Division  
New Orleans, La. 70189

for

Engineering Analysis Division

Johnson Space Center  
National Aeronautics and Space Administration  
Houston, Texas



WIND TUNNEL TEST SPECIFICS:

Test Number: MSFC 584  
NASA Series No.: IA-52  
Date: 12-17 Oct, 1973 (28 Occ. Hrs.)

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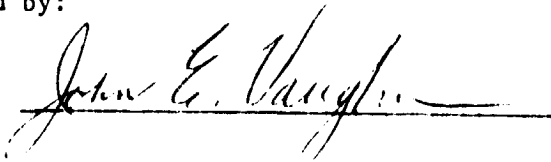
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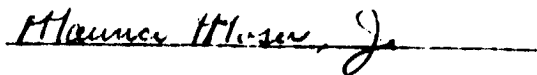
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Data Management Services



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RESULTS OF FLOW VISUALIZATION STUDIES  
IN THE NASA/MSFC 14 x 14 INCH TRISONIC WIND  
TUNNEL ON A .004 SCALE MODEL (34-0) SPACE  
SHUTTLE ORBITER AND INTEGRATED VEHICLE

By  
W. P. Carton\*

SUMMARY

This report presents details of flow visualization techniques developed during wind tunnel test IA-52 conducted in the NASA/MSFC 14 x 14 inch Trisonic Wind Tunnel. Testing was conducted from Mach = 0.9 to 5.0 on the orbiter alone and integrated vehicle configurations. Thin film oil paint and ultraviolet light sensitive oil applications were used on a .004 scale model vehicle. Test results presented herein are in the form of black and white photographs taken after the completion of a test run.

\* Rockwell International

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## TABLE OF CONTENTS

SUMMARY	iii
INDEX OF FIGURES	2
TEST FACILITY DESCRIPTION	5
CONFIGURATIONS INVESTIGATED	6
TEST PROCEDURE	8
DATA INTERPRETATION	11
TABLES	
I    TEST CONDITIONS	12
II   DATA SET COLLATIONS	13
III  MODEL DIMENSIONAL DATA	14

# INDEX OF FIGURES

<u>FIGURE</u>	<u>TITLE</u>	<u>PAGE</u>
1	General Arrangement of Orbiter Model	24
2	Oil Flow Photograph of Integrated Vehicle, $\alpha = \beta = 5^\circ$ , M = 0.9, Blue Oil Paint (Top View)	25
3	Oil Flow Photograph of Integrated Vehicle, $\alpha = \beta = 5^\circ$ , M = 0.9, Phosphor and Silicone Oil (Left Oblique)	26
4	Oil Flow Photograph of Integrated Vehicle, $\alpha = \beta = 5^\circ$ , M = 0.9, Blue Oil Paint (Right Oblique)	27
5	Oil Flow Photograph of Integrated Vehicle, $\alpha = \beta = 5^\circ$ , M = 1.2, Blue Oil Paint (Top View)	28
6	Oil Flow Photograph of Integrated Vehicle, $\alpha = \beta = 5^\circ$ , M = 1.2, Blue Oil Paint (Left Oblique)	29
7	Oil Flow Photograph of Integrated Vehicle, $\alpha = \beta = 5^\circ$ , M = 1.2, Blue Oil Paint (Right Oblique)	30
8	Oil Flow Photograph of Integrated Vehicle, $\alpha = 8^\circ$ , $\beta = 0^\circ$ , M = 0.9, Blue Oil Paint (Top View)	31
9	Oil Flow Photograph of Integrated Vehicle, $\alpha = 8^\circ$ , $\beta = 0^\circ$ , M = 0.9, Blue Oil Paint (Left Oblique)	32
10	Oil Flow Photograph of Integrated Vehicle, $\alpha = 8^\circ$ , $\beta = 0^\circ$ , M = 0.9, Blue Oil Paint (Right Oblique)	33
11	Oil Flow Photograph of Integrated Vehicle, $\alpha = 10^\circ$ , $\beta = 3^\circ$ , M = 4.96, Zyglo Solution (Top View)	34
12	Oil Flow Photograph of Integrated Vehicle, $\alpha = 10^\circ$ , $\beta = 3^\circ$ , M = 4.96, Red and Yellow Oil Paint (Left Oblique)	35
13	Oil Flow Photograph of Integrated Vehicle, $\alpha = 10^\circ$ , $\beta = 3^\circ$ , M = 4.96, Red and Yellow Oil Paint (Left Side)	36
14	Oil Flow Photograph of Integrated Vehicle, $\alpha = 10^\circ$ , $\beta = 3^\circ$ , M = 4.96, Red and Yellow Oil Paint (Right Oblique)	37

# INDEX OF FIGURES (Continued)

<u>FIGURE</u>	<u>TITLE</u>	<u>PAGE</u>
15	Oil Flow Photograph of Orbiter, $\alpha = \beta = 0^\circ$ , $M = 0.9$ , Blue Oil Paint (Top View)	38
16	Oil Flow Photograph of Orbiter, $\alpha = \beta = 0^\circ$ , $M = 0.9$ , Blue Oil Paint (Left Oblique)	39
17	Oil Flow Photograph of Orbiter, $\alpha = \beta = 0^\circ$ , $M = 0.9$ Blue Oil Paint (Right Oblique)	40
18	Oil Flow Photograph of Orbiter, $\alpha = 10^\circ$ , $\beta = 5^\circ$ , $M = 0.9$ , Blue Oil Paint (Top View)	41
19	Oil Flow Photograph of Orbiter, $\alpha = 10^\circ$ , $\beta = 5^\circ$ , $M = 0.9$ , Blue Oil Paint (Left Oblique)	42
20	Oil Flow Photograph of Orbiter, $\alpha = 10^\circ$ , $\beta = 5^\circ$ , $M = 0.9$ , Blue Oil Paint (Right Oblique)	43
21	Oil Flow Photograph of Orbiter, $\alpha = 10^\circ$ , $\beta = 5^\circ$ , $M = 1.96$ , Blue Oil Paint (Top View)	44
22	Oil Flow Photograph of Orbiter, $\alpha = 10^\circ$ , $\beta = 0^\circ$ , $M = 1.96$ , Blue Oil Paint (Left Oblique)	45
23	Oil Flow Photograph of Orbiter, $\alpha = 10^\circ$ , $\beta = 0^\circ$ , $M = 1.96$ , Blue Oil Paint (Right Oblique)	46
24	Oil Flow Photograph of Orbiter, $\alpha = 10^\circ$ , $\beta = 0^\circ$ , $M = 2.99$ , Blue Oil Paint (Top View)	47
25	Oil Flow Photograph of Orbiter, $\alpha = 10^\circ$ , $\beta = 0^\circ$ , $M = 2.99$ , Blue Oil Paint (Left Oblique)	48
26	Oil Flow Photograph of Orbiter, $\alpha = 10^\circ$ , $\beta = 0^\circ$ , $M = 2.99$ , Blue Oil Paint (Left Side)	49
27	Oil Flow Photograph of Orbiter, $\alpha = 10^\circ$ , $\beta = 0^\circ$ , $M = 2.99$ , Blue Oil Paint (Right Oblique)	50
28	Oil Flow Photograph of Orbiter, $\alpha = 10^\circ$ , $\beta = 0^\circ$ , $M = 4.96$ , Blue Oil Paint (Top View)	51
29	Oil Flow Photograph of Orbiter, $\alpha = 10^\circ$ , $\beta = 0^\circ$ , $M = 4.96$ , Blue Oil Paint (Left Oblique)	52



# INDEX OF FIGURES (Continued)

<u>FIGURE</u>	<u>TITLE</u>	<u>PAGE</u>
30	Oil Flow Photograph of Orbiter, $\alpha = 10^\circ$ , $\beta = 0^\circ$ , M = 4.96, Blue Oil Paint (Right Oblique)	53
31	Oil Flow Photograph of Model Preparation: Blue Oil Paint Brushed on and Wiped Down	54
32	Oil Flow Photograph of Model Preparation: Appearance after Spraying with Machine Tool Oil	55

## TEST FACILITY DESCRIPTION

The Marshall Space Flight Center 14" x 14" Transonic Wind Tunnel is an intermittent blowdown tunnel which operates by high pressure air flowing from storage to either vacuum or atmospheric conditions. A Mach number range from .2 to 5.85 is covered by using two interchangeable test sections. The transonic section permits testing at Mach 0.20 through 2.50 and the supersonic section permits testing at Mach 2.74 through 5.85. Mach numbers between .2 and .9 are obtained by using a controllable diffuser. The range from .95 to 1.3 is achieved through the use of plenum suction and perforated walls. Mach numbers of 1.44, 1.93 and 2.50 are produced by interchangeable sets of fixed contour nozzle blocks. Above Mach 2.50 a set of fixed contour nozzle blocks are tilted and translated automatically to produce any desired Mach number in .25 increments.

Air is supplied to a 6000 cubic foot storage tank at approximately -40°F dew point and 500 psi. The compressor is a three-stage reciprocating unit driven by a 1500 hp motor.

Tunnel flow is established and controlled with a servo-actuated gate valve. The controlled air flows through the valve diffuser into the stilling chamber and heat exchanger where the air temperature can be controlled from ambient to approximately 180°F. The air then passes through the test section which contains the nozzle blocks and test region.

Downstream of the test section is a hydraulically controlled pitch sector that provides a total angle of attack range of 20° ( $\pm 10^\circ$ ). Sting offsets are available for obtaining various maximum angles of attack up to 90°.

## CONFIGURATIONS INVESTIGATED

The 0.004-scale orbiter model general arrangement is shown in figure 1. The model has an aluminum wing and stainless steel body, vertical fin, and movable (interchangeable) surfaces. Data were taken with speed brake settings of:

$$\delta_{SB} \text{ (deg)} = 0, 24, 55.$$

The orbiter model was fabricated in conformance with the lines drawings listed below:

Nose	VL70-000143A
Mid-body and wing	VL70-000200
Aft body	VL70-000145
Vertical tail	VL70-000146A

The launch vehicle models (MSFC Model No. 453) were fabricated to 0.004-scale in conformance with the following configuration control drawings:

External Tank	VL78-000041B (except nose radius 30° vice 16.5° FS)
Solid Rocket Booster	VL77-000036A

The mated vehicle was assembled in accordance with the Shuttle Configuration Control Drawing VL72-000088D. Exact duplication of attached hardware and protuberances could not be maintained at 0.004-scale. Model fidelity, or lack thereof, in attachments and protuberances is indicated below:

<u>Component</u>	<u>Description</u>	<u>Model Fidelity</u>
AT <sub>5</sub>	Front Orb/ET Attach.	No: single vertical mounting post (.099" diam.) at same body station.
AT <sub>6</sub> , AT <sub>7</sub>	Left and Right Rear Orb/ET Attach.	Yes
AT <sub>8</sub> , AT <sub>9</sub>	Front and Rear SRB/ET Attach.	No: single stand-off post mount .182" in diam. at approximately same body stations on ET 4.
FL <sub>1</sub> , FL <sub>2</sub>	LOX and LH <sub>2</sub> Feedlines	Yes: represented by aft model orbiter/ET mounting posts (0.187" diam.) at correct body station.
FR <sub>1</sub>	Umbilical Door Fairing	Absent.
FR <sub>2</sub>	Splash Shield (LOX and LH <sub>2</sub> )	Absent.
PS <sub>1</sub>	SRB Electrical Tunnel	Absent.
PS <sub>2</sub>	SRB Aft Attach Ring	Yes.
PS <sub>3</sub>	Separation Rocket Fairing	Yes.
PT <sub>1</sub>	LOX Vent Line Fairing	Yes.
PT <sub>2</sub>	LOX Feedline	Yes.
PT <sub>3</sub>	LH <sub>2</sub> Vent Line	Yes.

Model dimensional data sheets defining the various configuration designators are provided in Table III. The model components tested were:

B26	orbiter body
C9	canopy
R5	rudder
V8	vertical tail
W116	wing, basic

F7	body flap
E26	elevon
M7	OMS pods
S12	Solid Rocket Booster with Attach ring (PS2) and Separation Rocket Fairing (PS3)
T14	External Tank with LOX and LH <sub>2</sub> vent lines and LOX feed line (PT1,2,3)

#### TEST PROCEDURE

##### Model Preparation

The model parts were cleaned of oil and grease before assembly and then again after assembly to aid adhesion of the filler. All gaps, nicks, and screw slots were filled with polyester resin (auto body) filler so that no pockets for pigment or solvent remained. Final contouring was accomplished with #600 wet aluminum oxide paper.

The model was lightly degreased and then sprayed with white lacquer in several medium coats. Imperfections then evident were touched up with filler and # 600 paper. The model was then resprayed with lacquer and allowed to dry at least one hour following achievement of an acceptable finish. The color coat was then sealed with several coats of clear lacquer, as it has been found that the oil paint pigments tend to adhere to the color coat. The model should be allowed to dry overnight if possible; hardware and facility schedules did not permit this long a drying period for this test. The effects of surface imperfections may be noted in many of the photographs; Figure 11 shows these effects very clearly.

#### Medium Preparation

Red, yellow, and prussian blue oil paints were mixed with artist's linseed oil in the approximate proportions (by volume) shown below. It is believed that best results with black and white photography will be obtained with black or prussian blue oil paints.

Pigment	Linseed Oil	Mach No.	P <sub>o</sub>
1	1	1.0	22
1	1.5 to 2.0	2.0	28
1	2.5 to 3.0	3.0	30
1	2.5 to 4.5 (?)	5.0	90

A medium composed of a mixture of silicone oil, silicone stopcock grease, and phosphor powder mixed to the consistence of thin pancake batter was found to be effective at  $0.9 \leq M \leq 1.2$ . It is believed that it would be necessary to thin the mixture as Mach number increases. Enough phosphor should be used to provide ample pigmentation. Ultraviolet illumination of the model during the run to observe flow pattern development (and decide when to terminate the run) is required using either the phosphor or a "Zyglo" solution medium. Ultraviolet lighting is also required for black and white post-run photography of the model. The longer exposure times were found to permit puddling or running of the flow pattern on the model with the thin medium used at the higher Mach numbers. Figures 3 and 11 are examples of the results obtained with the phosphor/oil/silicone grease and the Zyglo solution, respectively.

### Application

Oil Film - There was a tendency to apply too much pigment, with puddling and subsequent running during the post-run photography of the model. Better results were obtained with a thin coat of paint applied with an artist's brush (# 5 or # 6 is good) and then wiped off evenly with a facial tissue so that a thin film of pigment remained (Figure 31). The wipe pattern may be removed if desired by lightly spraying (from a distance of approximately 12") with an aerosol can of machine tool oil; an atomizer and linseed oil would also work. This produces a dappled appearance (Figure 32).

Phosphor - This was also brushed on thinly, but not wiped down. The same technique was used with the Zyglon solution.

### Data Runs

Runs should be long enough to develop a pattern and blow away excess medium if possible. The appearance of the model during the run was monitored through glass walls and the run terminated on visual cues. Typical blows were 20-25 seconds in the transonic range, but as brief as 10 seconds at  $M > 3.0$ .

### Photography

Black and white photography was employed to record the run results. Motion pictures are feasible with the oil paint technique. It may be desirable to open the tunnel immediately after the blow and roll the model to minimize running of the thin medium at higher Mach numbers. As previously mentioned, this problem is compounded with the fluorescing medium because of the longer exposure times required.

#### Model Clean-Up

The chosen cleaning method was to paint the model with liquid soap and rinse with hot water. Mineral spirits may also be used.

#### DATA INTERPRETATION

The data (Figures 2 through 30) obtained in this test have been (and are to be) used only for qualitative evaluation of flow characteristics in the selected flight conditions. Quantitative results will require more rigorous control of camera look angles than was provided in this study.



TABLE I. TEST CONDITIONS

[illegible]

TABLE II.

TEST: TWI 584 (TA-52)										DATA SET/RUN NUMBER COLLATION SUMMARY																	DATE:	
DATA SET IDENTIFIER		CONFIGURATION		SCHD.		PARAMETERS/VALUES										MACH NUMBERS												
				A	B	$\phi$	L <sub>0</sub>	Z <sub>0</sub>	S <sub>0A</sub>								0.9	1.2	1.96	2.99	4.96							
	$\phi_{34}$ T14 S12			5	5	270	0	34"	0								1	2										
				8	0	0	0	34"	0								3											
				10	3	270	0	34"	0											4								
	$\phi_{34}$			0	0	0	-	-	24								5											
				10	5	270	-	-	24								6											
				10	0	0	-	-	55									7	8	9								

TABLE III. MODEL DIMENSIONAL DATA

MODEL COMPONENT: BODY - B<sub>0</sub>

GENERAL DESCRIPTION: Orbiter Fuselage Configuration 140 A/B

NOTE: B<sub>0</sub> identical to B<sub>1</sub> except underside of fuselage refaired to accept W<sub>116</sub>.

Model Scale = .004

DRAWING NUMBER:

VL70-000193

VL70-000140A

DIMENSIONS:

FULL-SCALE

MODEL SCALE

Length (Body Fwd Sta X<sub>0</sub> = 238) - in.

1290.3

5.16120

Max. Width (at X<sub>0</sub> = 1520) - in.

262.0

1.04800

Max. Depth (at X<sub>0</sub> = 1464) - in.

250.0

1.000

Fineness Ratio

4.92481

4.92481

Area - ft<sup>2</sup>

Max. Cross-Sectional

340.88462

0.00545

Planform

Wetted

Base

TABLE III. (Continued)

MODEL COMPONENT: Canopy-CO

GENERAL DESCRIPTION: Configuration 3A

Model Scale = .004

DRAWING NUMBER VL70-00014CA  
VL70-000143A

<u>DIMENSION:</u>	<u>FULL SCALE</u>	<u>MODEL SCALE</u>
Length ( $X_0=434.643$ to $670$ )	<u>235.357</u>	<u>0.94143</u>
Max Width ( $X_0=513.127$ )	<u>152.412</u>	<u>0.60955</u>
Max Depth ( $X_0=485.0$ )	<u>25.000</u>	<u>0.10000</u>
Fineness Ratio	<u>          </u>	<u>          </u>
Area	<u>          </u>	<u>          </u>
Max Cross-Sectional	<u>          </u>	<u>          </u>
Planform	<u>          </u>	<u>          </u>
Wetted	<u>          </u>	<u>          </u>
Base	<u>          </u>	<u>          </u>

TABLE III. (Continued)

MODEL COMPONENT: R5 - RudderGENERAL DESCRIPTION: 2A and 3 configuration per Rockwell linesVL70-000095 and VL70-000139Scale Model = .004DRAWING NUMBER:VL70-000139  
VL70-000095DIMENSIONS:FULL-SCALEMODEL SCALEArea ~ Ft<sup>2</sup>106.380.00170

Span (equivalent) ~ IN.

201.00.8040

Inb'd equivalent chord

91.5850.36634

Outb'd equivalent chord

50.8330.20333Ratio movable surface chord/  
total surface chord

At Inb'd equiv. chord

0.4000.400

At Outb'd equiv. chord

0.4000.400

Sweep Back Angles, degrees

Leading Edge

34.8334.83

Tailing Edge

26.2526.25

Hingeline

34.8334.83Area Moment (Normal to hinge line) Ft<sup>3</sup>526.130.00003

Product of area and mean chord

TABLE III. (Continued)

MODEL COMPONENT: WING-W116GENERAL DESCRIPTION: Configuration 4NOTE: Identical to W116 except airfoil thickness. Dihedral angle is along  
trailing edge of wing.

Model Scale = .004

TEST NO.	DWG. NO. <u>VL70-0001108</u> <u>VL70-0001110</u>	
DIMENSIONS:	FULL-SCALE	MODEL SCALE
<u>TOTAL DATA</u>		
Area (Theo.) $\text{Ft}^2$		
Planform	2690.00	0.4304
Span (Theo) In.	936.6816	3.74572
Aspect Ratio	2.265	2.265
Rate of Taper	1.177	1.177
Taper Ratio	0.200	0.200
Dihedral Angle, degrees (at $X_0=1506.623, Y_0=$	3.500	3.500
Incidence Angle, degrees 105, $Z_0=282.75$ )	0.500	0.500
Aerodynamic Twist, degrees	+3.000	+3.000
Sweep Back Angles, degrees		
Leading Edge	45.00	45.00
Trailing Edge	-10.056	-10.056
0.25 Element Line	35.209	35.209
Chords:		
Root (Theo) B.P.O.O.	689.2429	2.75697
Tip, (Theo) B.P.	137.8486	0.55137
MAC	474.8117	1.89225
Fus. Sta. of .25 MAC	1126.721	4.50045
W.P. of .25 MAC	291.00	1.16400
B.L. of .25 MAC	187.55491	0.74254
<u>EXPOSED DATA</u>		
Area (Theo) $\text{Ft}^2$	1812.2205	0.02899
Span, (Theo) In. BP108	736.6816	2.94613
Aspect Ratio	2.058	2.058
Taper Ratio	0.2451	0.2451
Chords		
Root BP108	570.6230	2.28249
Tip 1.00 $\frac{b}{2}$	137.8512	0.55140
MAC	354.2376	1.41695
Fus. Sta. of .25 MAC	1164.237	4.65695
W.P. of .25 MAC	292.00	1.16600
B.L. of .25 MAC	239.67786	0.95671
Airfoil Section (Rockwell Mod NASA)		
XXXX-64		
Root $\frac{b}{2} = 0.425$	0.113	0.113
Tip $\frac{b}{2} = 1.00$	0.12	0.12
Data for (1) of (2) Sides		
Leading Edge Cuff $\frac{b}{2}$	118.333	0.00189
Planform Area $\text{Ft}^2$	505.0	2.02000
Leading Edge Intersects Fus M. L. @ Sta	1003.5	4.01400
Leading Edge Intersects Wing @ Sta		

TABLE III. (Continued)

MODEL COMPONENT: Body Flap - F<sub>7</sub>GENERAL DESCRIPTION: Configuration 3A

NOTE: Body flap has variable centerline deflection of  $-13.75^\circ$  and  $-24.05^\circ$  from null position. Winge line located at  $X_0 = 1522.3$ .

 $Z_0 = 284.3$ 

Model Scale = .004

DRAWING NUMBER VI.70-000140A, VI.70-000145

<u>DIMENSION:</u>	<u>FULL SCALE</u>	<u>MODEL SCALE</u>
Length( $X_0=1520$ to $X_0=1613$ ) - IN.	<u>93.000</u>	<u>0.372</u>
Max Width - IN.	<u>262.000</u>	<u>1.048</u>
Max Depth ( $X_0 = 1520$ ) - IN.	<u>23.000</u>	<u>0.092</u>
Fineness Ratio	<u>          </u>	<u>          </u>
Area - Ft <sup>2</sup>	<u>          </u>	<u>          </u>
Max Cross-Sectional	<u>          </u>	<u>          </u>
Planform	<u>150.5250</u>	<u>0.00241</u>
Wetted	<u>          </u>	<u>          </u>
Base	<u>41.84722</u>	<u>0.00067</u>

TABLE III. (Continued)

MODEL COMPONENT: FINCH - E<sub>26</sub>GENERAL DESCRIPTION: Configuration 4NOTE: VL70-000400 data for (1) of (2) sides. Identical to E<sub>25</sub> except  
airfoil thickness

Model Scale = .004

DRAWING NUMBER: VL70-000200  
VL70-000140 B

<u>DIMENSIONS:</u>	<u>FULL-SCALE</u>	<u>MODEL SCALE</u>
Area ft.	<u>223.5814</u>	<u>0.00358</u>
Span (equivalent) in.	<u>368.24</u>	<u>1.47336</u>
Inb'd equivalent chord in.	<u>119.623</u>	<u>0.47849</u>
Outb'd equivalent chord in.	<u>55.1922</u>	<u>0.22077</u>
Ratio movable surface chord/ total surface chord		
At Inb'd equiv. chord	<u>0.2096</u>	<u>0.2096</u>
At Outb'd equiv. chord	<u>0.4004</u>	<u>0.4004</u>
Sweep Back Angles, degrees		
Leading Edge	<u>0.00</u>	<u>0.00</u>
Tailing Edge	<u>-10.056</u>	<u>-10.056</u>
Hingeline	<u>0.00</u>	<u>0.00</u>
Area Moment (Normal to hinge line)	<u>851.1502</u>	<u>0.00005</u>



TABLE III. (Continued)

MODEL COMPONENT: OUT FOD - X<sub>0</sub>

GENERAL DESCRIPTION: Configuration 3A

Model Scale = .001

DRAWING NUMBER VL70-000140A  
VL70-000145

<u>DIMENSION:</u>	<u>FULL SCALE</u>	<u>MODEL SCALE</u>
Length (O/S Fwd Sta X <sub>0</sub> =1233.0) - IN.	<u>327.000</u>	<u>1.30800</u>
Max Width (O X <sub>0</sub> =1450.0) - IN.	<u>94.5</u>	<u>0.37800</u>
Max Depth (O X <sub>0</sub> =1493.0) - IN.	<u>109.000</u>	<u>0.43600</u>
Fineness Ratio	<u></u>	<u></u>
Area		
Max Cross-Sectional	<u></u>	<u></u>
Planform	<u></u>	<u></u>
Wetted	<u></u>	<u></u>
Base	<u></u>	<u></u>

TABLE III. (Continued)

MODEL COMPONENT: VERTICAL - VGENERAL DESCRIPTION: Configuration 3a

NOTE: Similar to V5 with radius on TE upper corner and LE lower corner  
where vertical meets fuselage.

Model Scale = .004

DRAWING NUMBER:

VL70-000140

VL70-000141

DIMENSIONS:

FULL-SCALE

MODEL SCALE

TOTAL DATA

Area (Theo) $\text{Ft}^2$	413.253	0.00561
Planform		
Span (Theo) In	315.720	1.26288
Aspect Ratio	1.65	1.65
Rate of Taper	0.532	0.532
Taper Ratio	0.40369	0.40369
Sweep Back Angles, degrees		
Leading Edge	45.00	45.00
Trailing Edge	25.947	25.947
0.25 Element Line	41.150	0.16460
Chords:		
Root (Theo) WP	268.500	1.07400
Tip (Theo) WP	103.470	0.41388
MAC	190.000	0.76000
Fus. Sta. of .25 MAC	1463.50	5.85400
W. P. of .25 MAC	635.502	2.54201
B. L. of .25 MAC	0.00	0.00
Airfoil Section		
Leading Wedge Angle Deg	10.00	10.00
Trailing Wedge Angle Deg	14.922	14.922
Leading Edge Radius (in) - IN.	2.00	0.00800
Void Area	13.17	0.00051
Blanketed Area	0.00	0.00

TABLE III. (Continued)

MODEL COMPONENT: BOOSTER SOLID ROCKET MOTOR - NRGENERAL DESCRIPTION: Configuration 3A, Data for (1) of (2)  
sides, per Rockwell Lines VL77-000036AModel Scale = 0.004DRAWING NUMBER: VL72-000088A  
VL77-000036A

<u>DIMENSIONS:</u>	<u>FULL-SCALE</u>	<u>MODEL SCALE</u>
Length (Includes Nozzle) - IN.	<u>1741.0</u>	<u>6.9640</u>
Max. Width (Tank Dia) - IN.	<u>142.3</u>	<u>0.5692</u>
Max. Depth (Aft Shroud) - IN.	<u>192.0</u>	<u>0.7680</u>
Fineness Ratio	<u>9.06771</u>	<u>9.06771</u>
Area - FT <sup>2</sup>		
Max. Cross-Sectional	<u>201.06193</u>	<u>0.00322</u>
Planform	<u>          </u>	<u>          </u>
Wetted	<u>          </u>	<u>          </u>
Base	<u>          </u>	<u>          </u>
WP of BSRM Centerline ( $Z_T$ ) - IN.	<u>400</u>	<u>1.6000</u>
FS of BSRM Nose ( $X_T$ ) - IN.	<u>200</u>	<u>0.8000</u>

Table III. (Concluded)

MODEL COMPONENT: EXTERNAL TANK - T<sub>14</sub>

GENERAL DESCRIPTION: \_\_\_\_\_

NOTE: T<sub>14</sub> identical to T<sub>9</sub> but with external fuel lines added.

Model Scale = 0.004

DRAWING NUMBER: VL78-000018

<u>DIMENSIONS:</u>	<u>FULL-SCALE</u>	<u>MODEL SCALE</u>
Length - IN.	<u>1858</u>	<u>7.432</u>
Max. Width (Dia) - IN.	<u>324.0</u>	<u>1.296</u>
Max. Depth	<u>          </u>	<u>          </u>
Fineness Ratio - L/D	<u>5.73457</u>	<u>5.73457</u>
Area - FT <sup>2</sup>		
Max. Cross-Sectional	<u>572.56</u>	<u>0.009161</u>
Planform	<u>          </u>	<u>          </u>
Wetted	<u>          </u>	<u>          </u>
Base	<u>          </u>	<u>          </u>

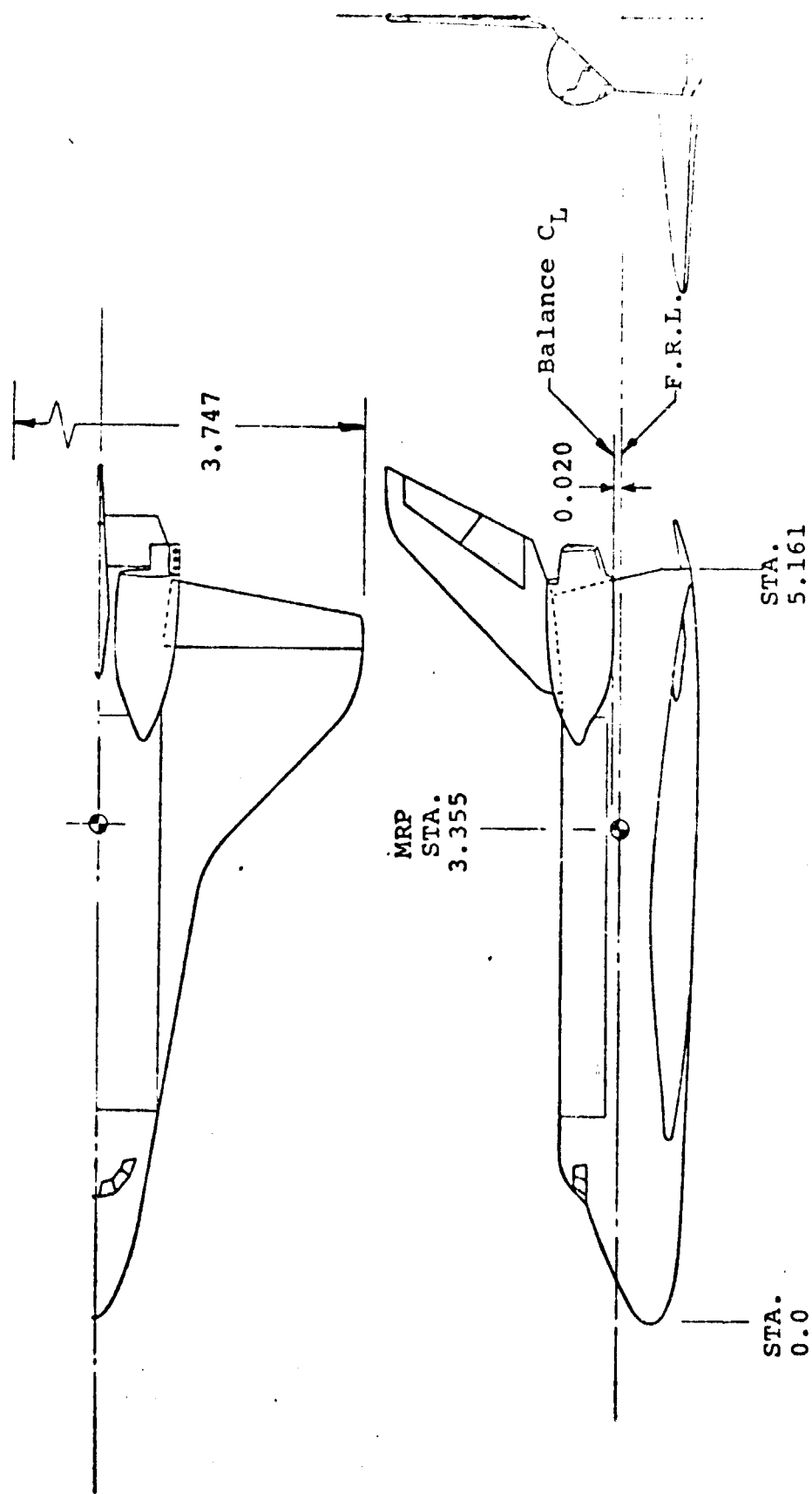


FIGURE 1. - General Arrangement of Orbiter Model

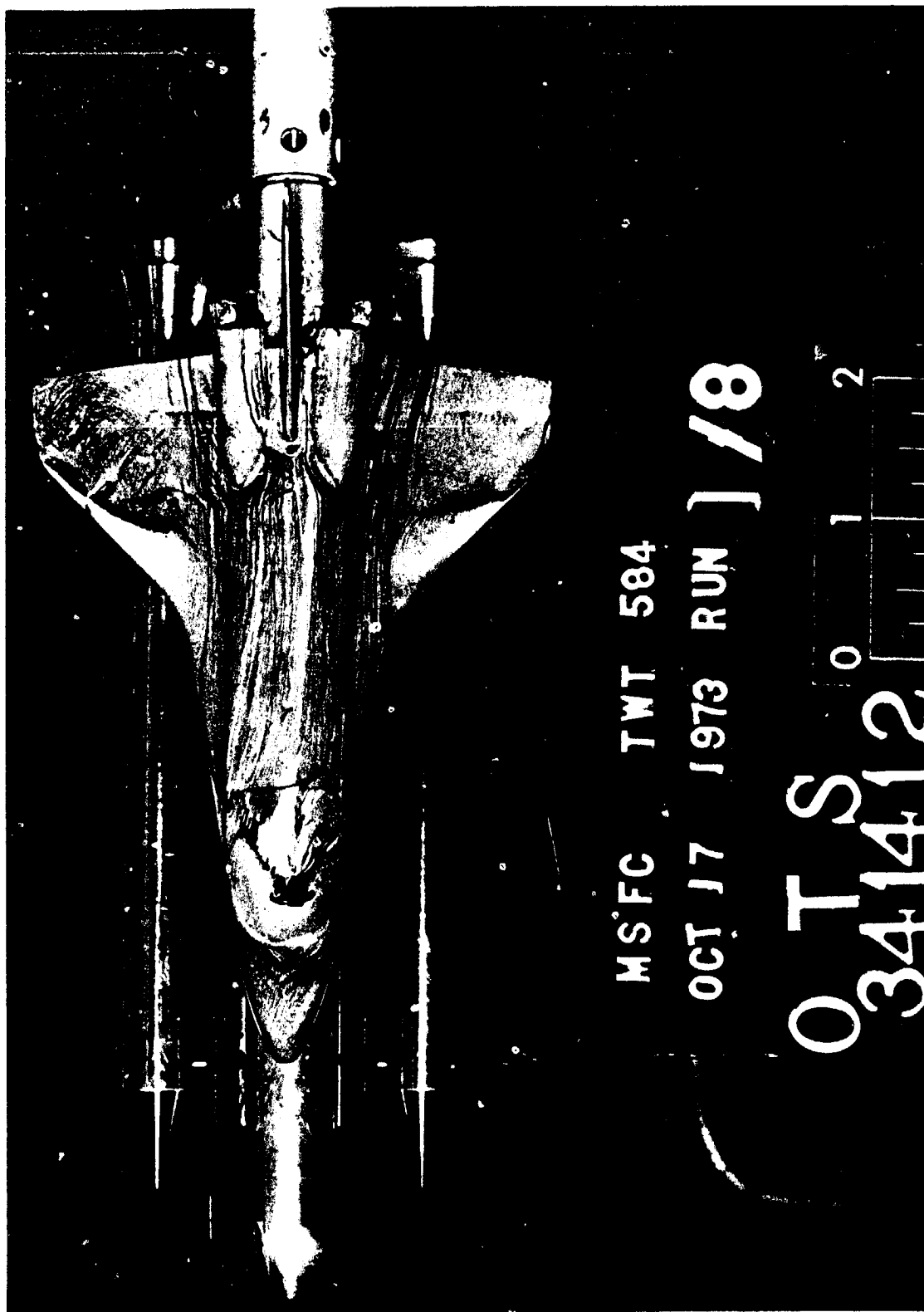


FIGURE 2. OIL FLOW PHOTOGRAPH OF INTEGRATED VEHICLE;  $\alpha = \beta = 5^\circ$ ,  $M = 0.9$ ,  
BLUE OIL PAINT (TOP VIEW)

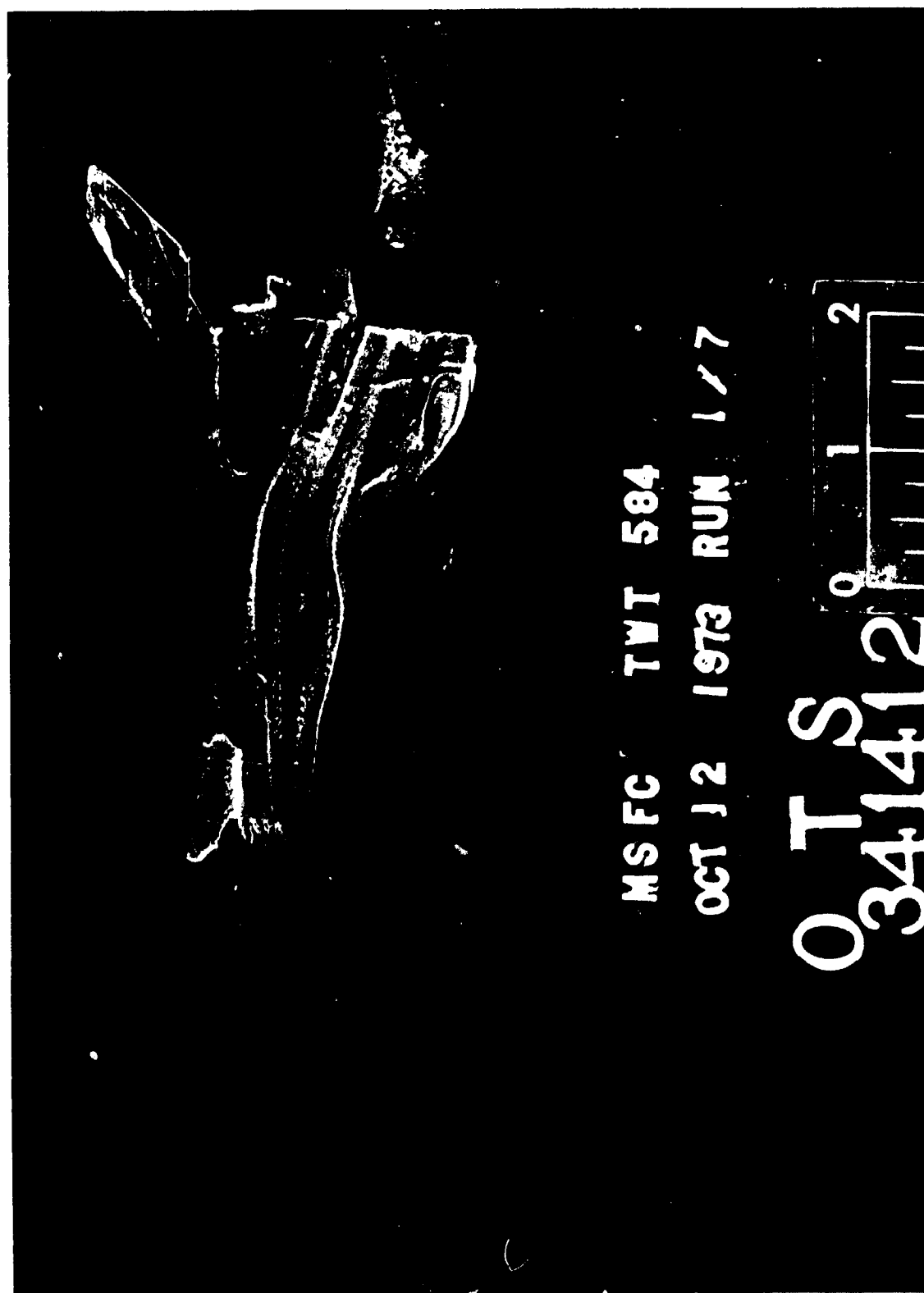
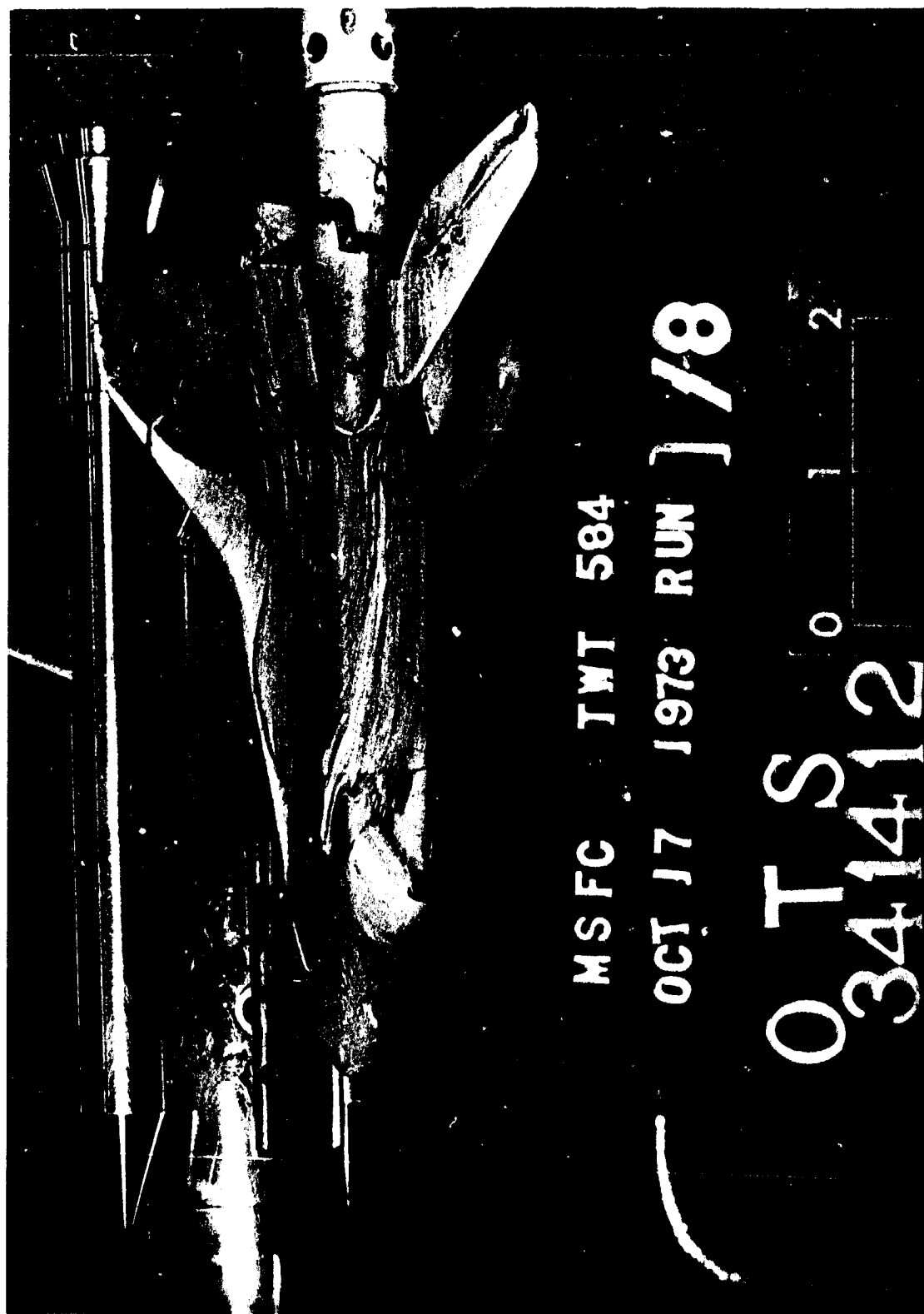


FIGURE 3. OIL FLOW PHOTOGRAPH OF INTEGRATED VEHICLE,  $\alpha = \beta = 5^\circ$ ,  $M = 0.9$ , PHOSPHOR AND SILICONE OIL (LEFT OBLIQUE)



MSFC TWT 584

OCT 17 1973 RUN 18

OTS<sup>0</sup>  
341412 1 2

FIGURE 4. OIL FLOW PHOTOGRAPH OF INTEGRATED VEHICLE,  $\alpha = 5^\circ$ ,  $M = 0.9$ ,  
BLUE OIL PAINT (RIGHT OBLIQUE)



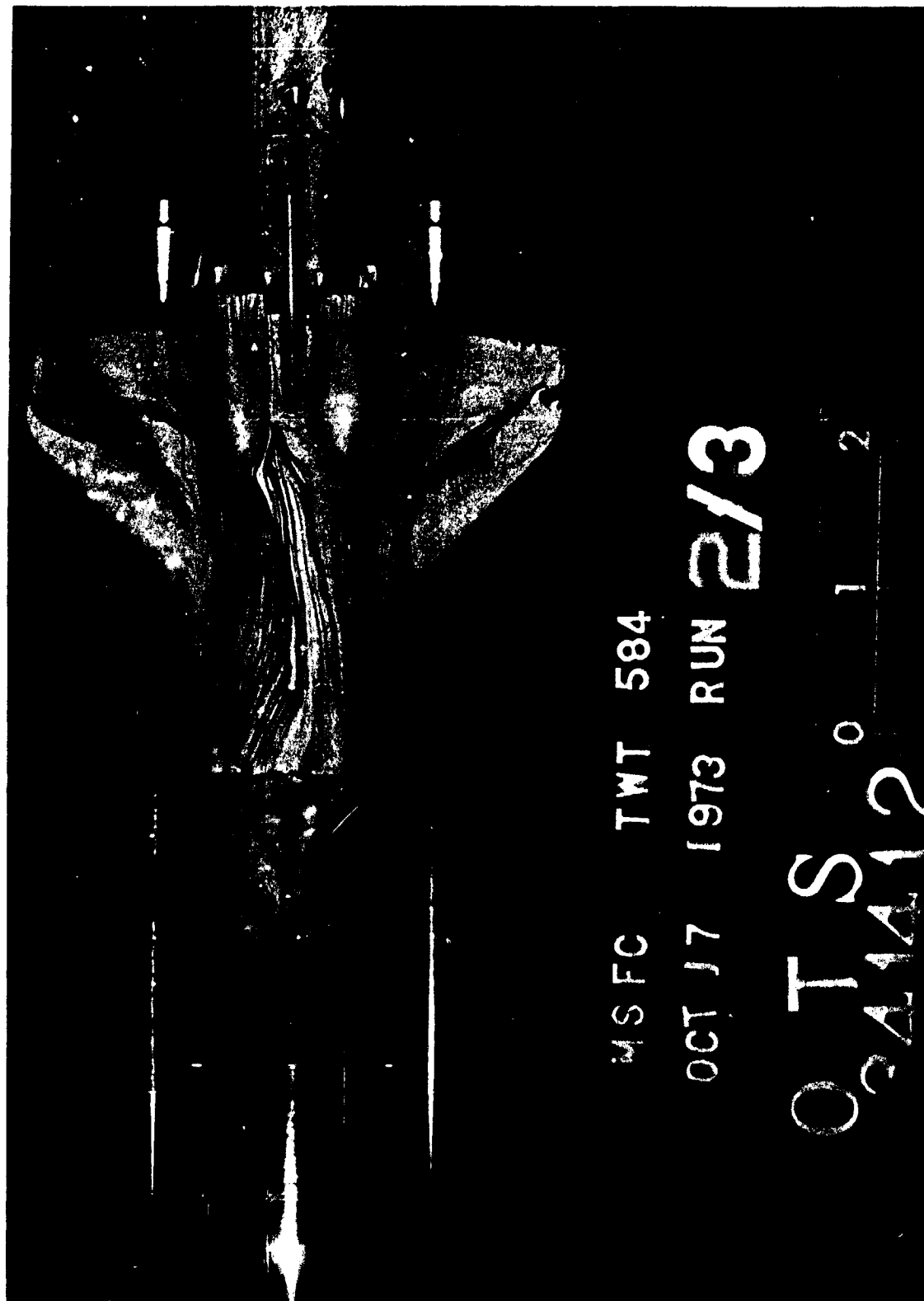
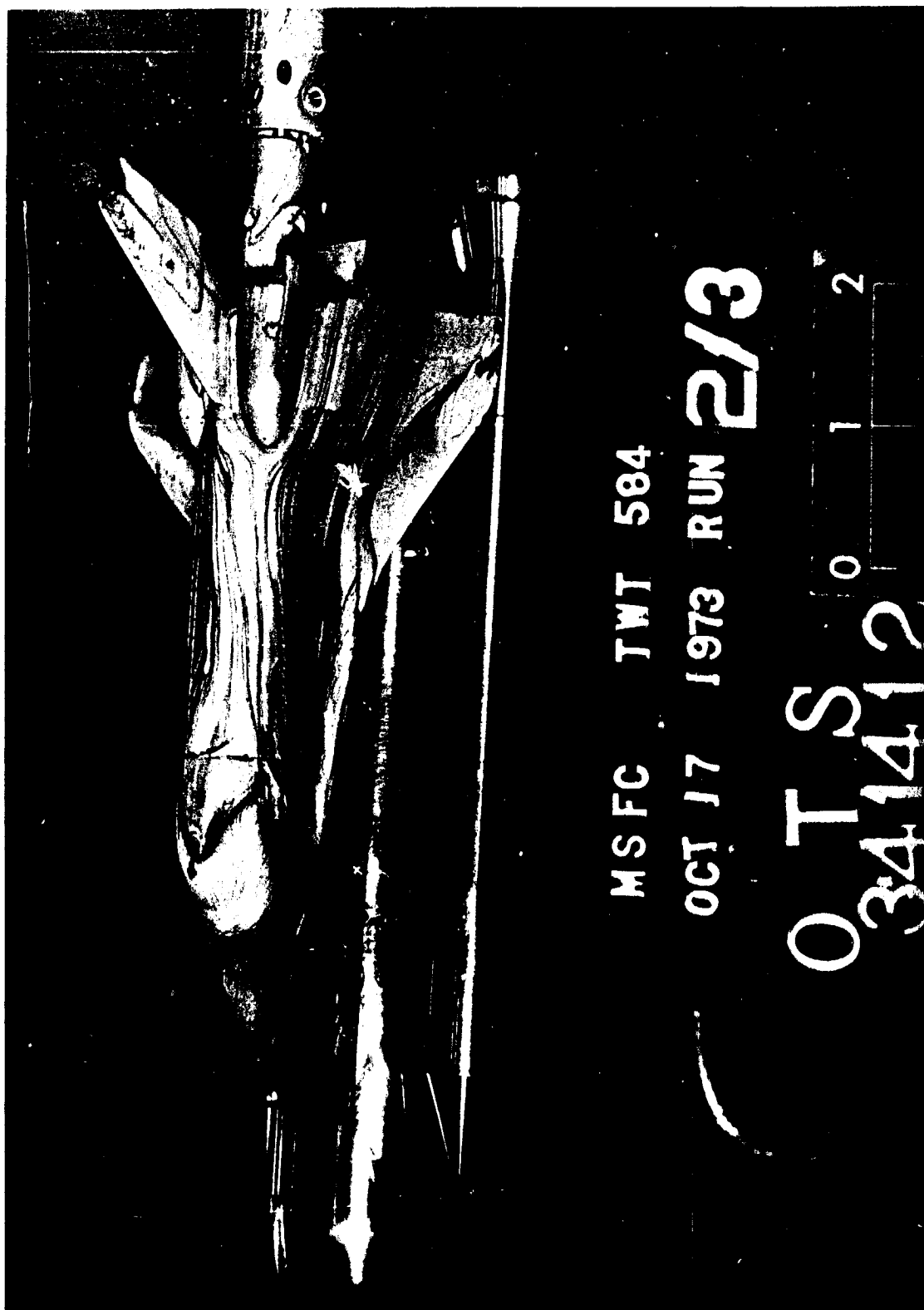


FIGURE 5. OIL FLOW PHOTOGRAPH OF INTEGRATED VEHICLE,  $\alpha = \beta = 5^\circ$ ,  $M = 1.2$ ,  
BLUE OIL PAINT (TOP VIEW)



MSFC TWT 584

OCT 17 1973 RUN 2/3

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FIGURE 6. OIL FLOW PHOTOGRAPH OF INTEGRATED VEHICLE,  $\alpha = \beta = 5^\circ$ ,  $M = 1.2$ ,  
BLUE OIL PAINT (LEFT OBLIQUE)



MSFC TWT 58 2

OCT 17 1973 RUN 2/3

OTS 0 1 2  
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FIGURE 7. OIL FLOW PHOTOGRAPH OF INTEGRATED VEHICLE,  $\alpha = 8^\circ$ ,  $\beta = 5^\circ$ ,  $M = 1.2$ ,  
BLUE OIL PAINT (RIGHT OBLIQUE)

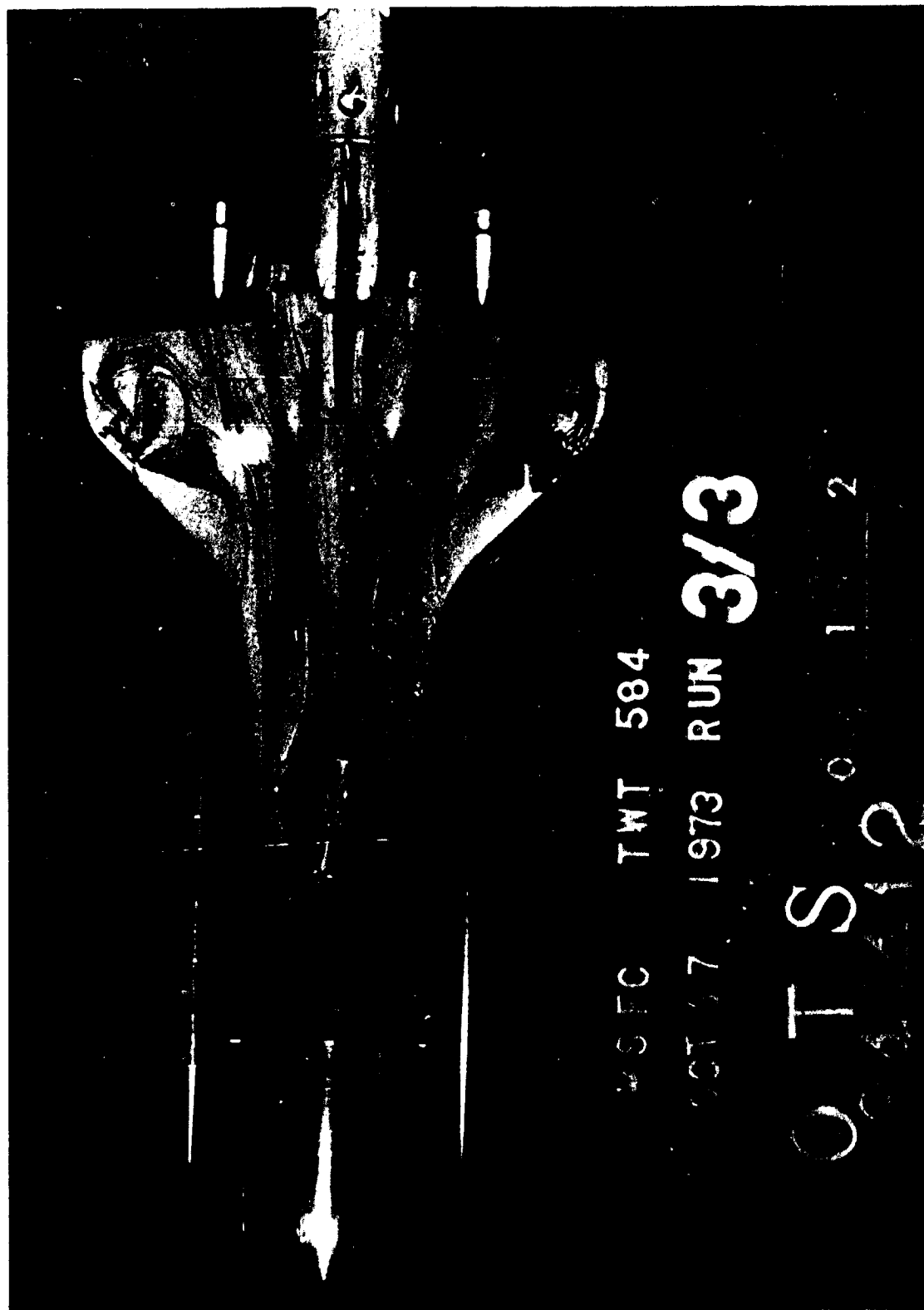
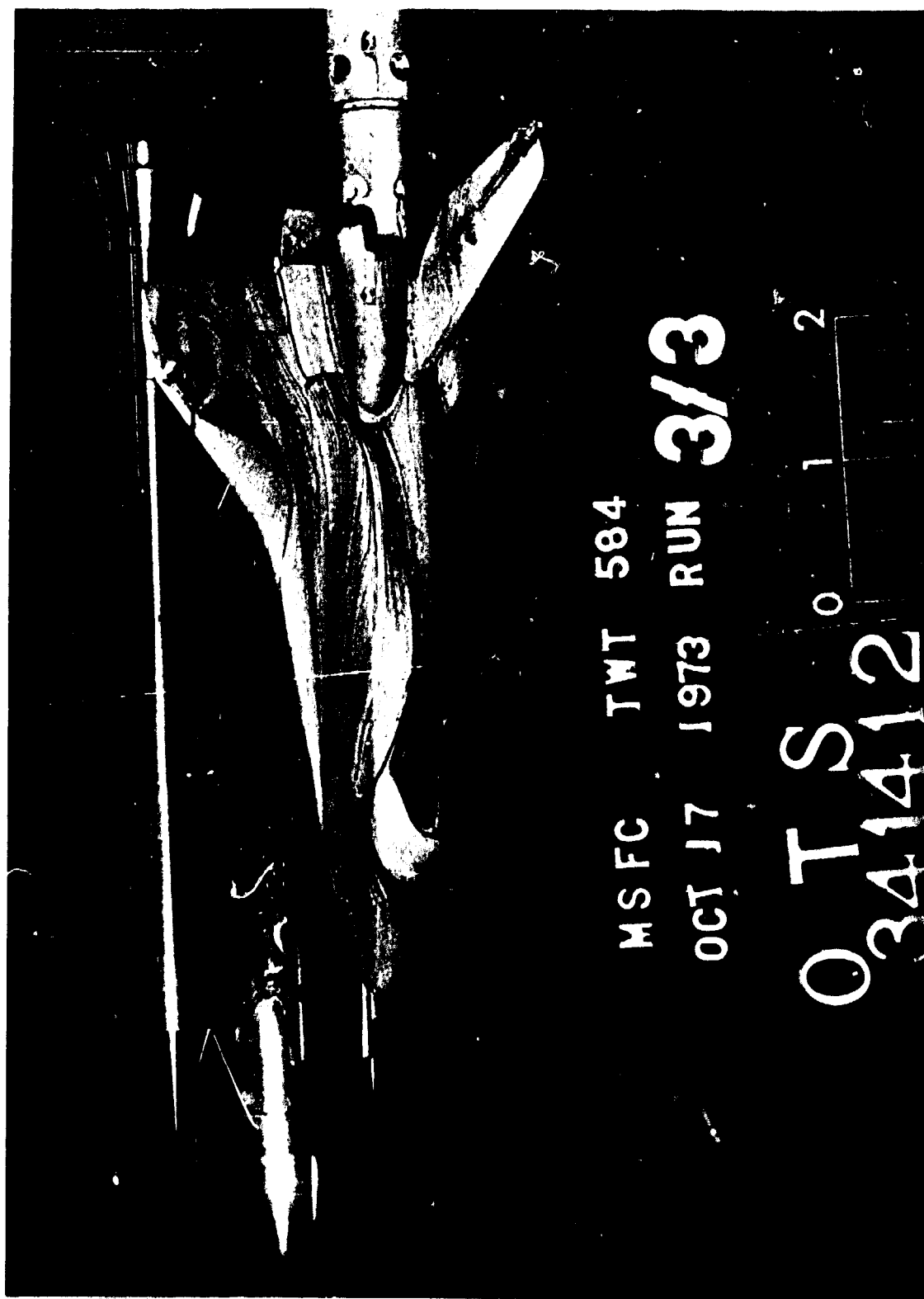


FIGURE 8. OIL FLOW PHOTOGRAPH OF INTEGRATED VEHICLE,  $\alpha = 8^\circ$ ,  $\beta = 0^\circ$ ,  $M = 0.9$ ,  
BLUE OIL PAINT (TOP VIEW)



FIGURE 9. OIL FLOW PHOTOGRAPH OF INTEGRATED VEHICLE,  $\alpha = 8^\circ$ ,  $\beta = 0^\circ$ ,  $M = 0.9$ ,  
BLUE OIL PAINT (LEFT OBLIQUE)



MSFC TWT 584

OCT 17 1973 RUN 3/3

OTS<sup>0</sup>  
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FIGURE 10. OIL FLOW PHOTOGRAPH OF INTEGRATED VEHICLE,  $\alpha = 8^\circ$ ,  $\beta = 0^\circ$ ,  $M = 0.9$ ,  
BLUE OIL PAINT (RIGHT OBLIQUE)



FIGURE 11. OIL FLOW PHOTOGRAPH OF INTEGRATED VEHICLE,  $\alpha = 10^\circ$ ,  $\beta = 3^\circ$ ,  $M = 4.96$ , ZYGLO SOLUTION (TOP VIEW)

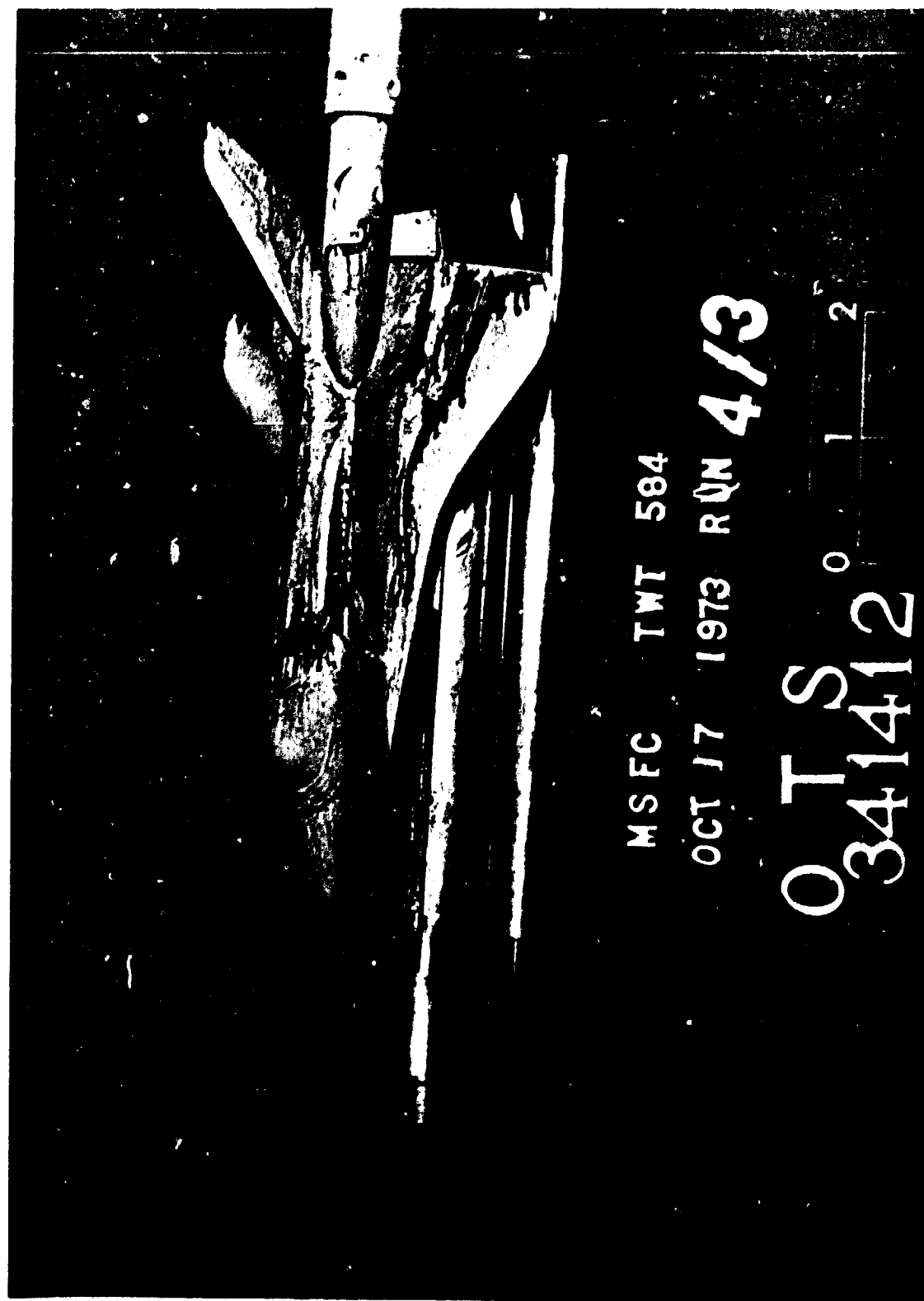
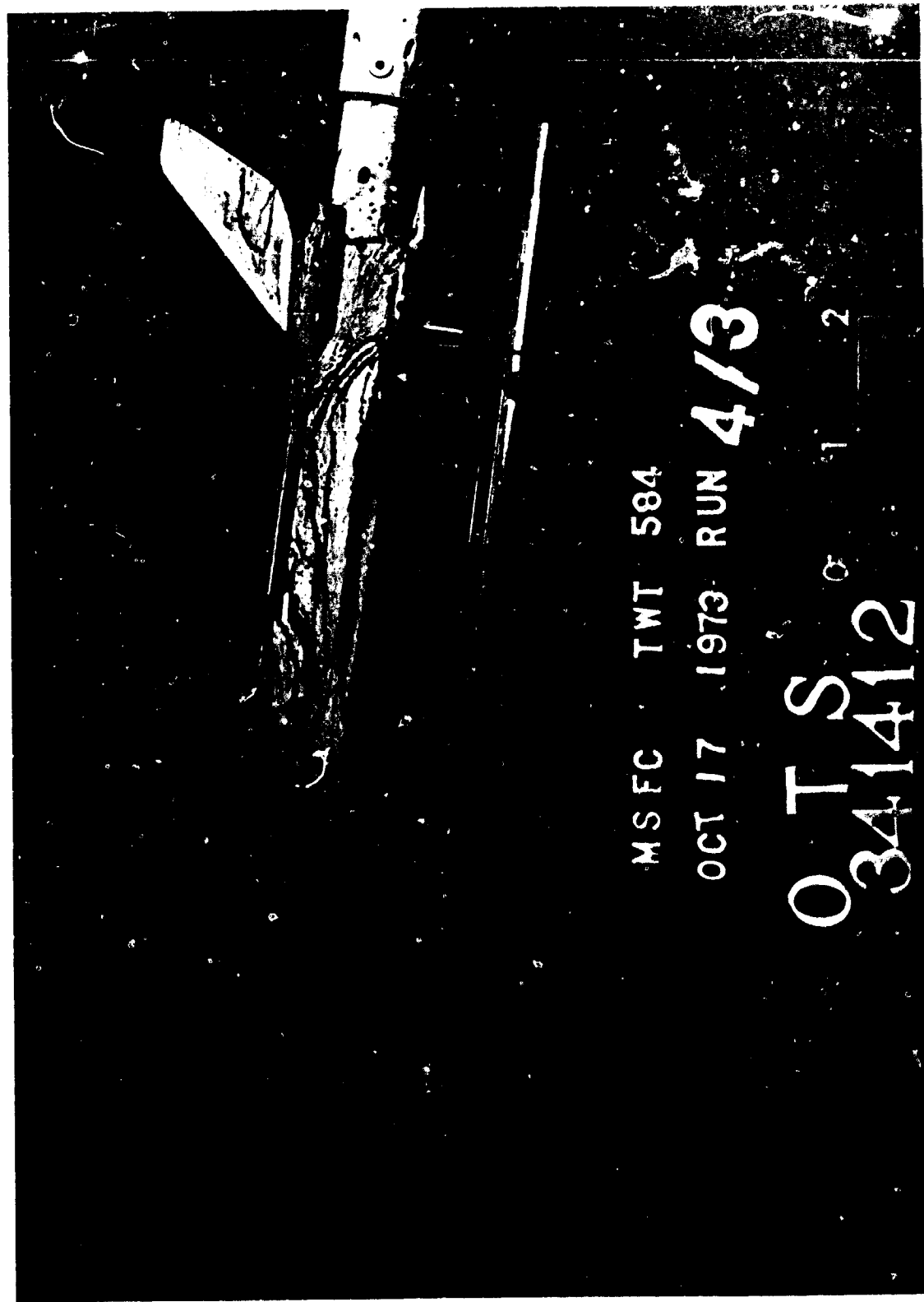


FIGURE 12. OIL FLOW PHOTOGRAPH OF INTEGRATED VEHICLE,  $\alpha = 10^\circ$ ,  $\beta = 3^\circ$ ,  $M = 4.96$ ,  
RED AND YELLOW OIL PAINT (LEFT OBLIQUE)





MSFC TWT 584

OCT 17 1973 RUN 4/3

OTS  
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FIGURE 13. OIL FLOW PHOTOGRAPH OF INTEGRATED VEHICLE,  $\alpha = 10^\circ$ ,  $\beta = 3^\circ$ ,  $M = 4.96$ ,  
RED AND YELLOW OIL PAINT (LEFT SIDE)

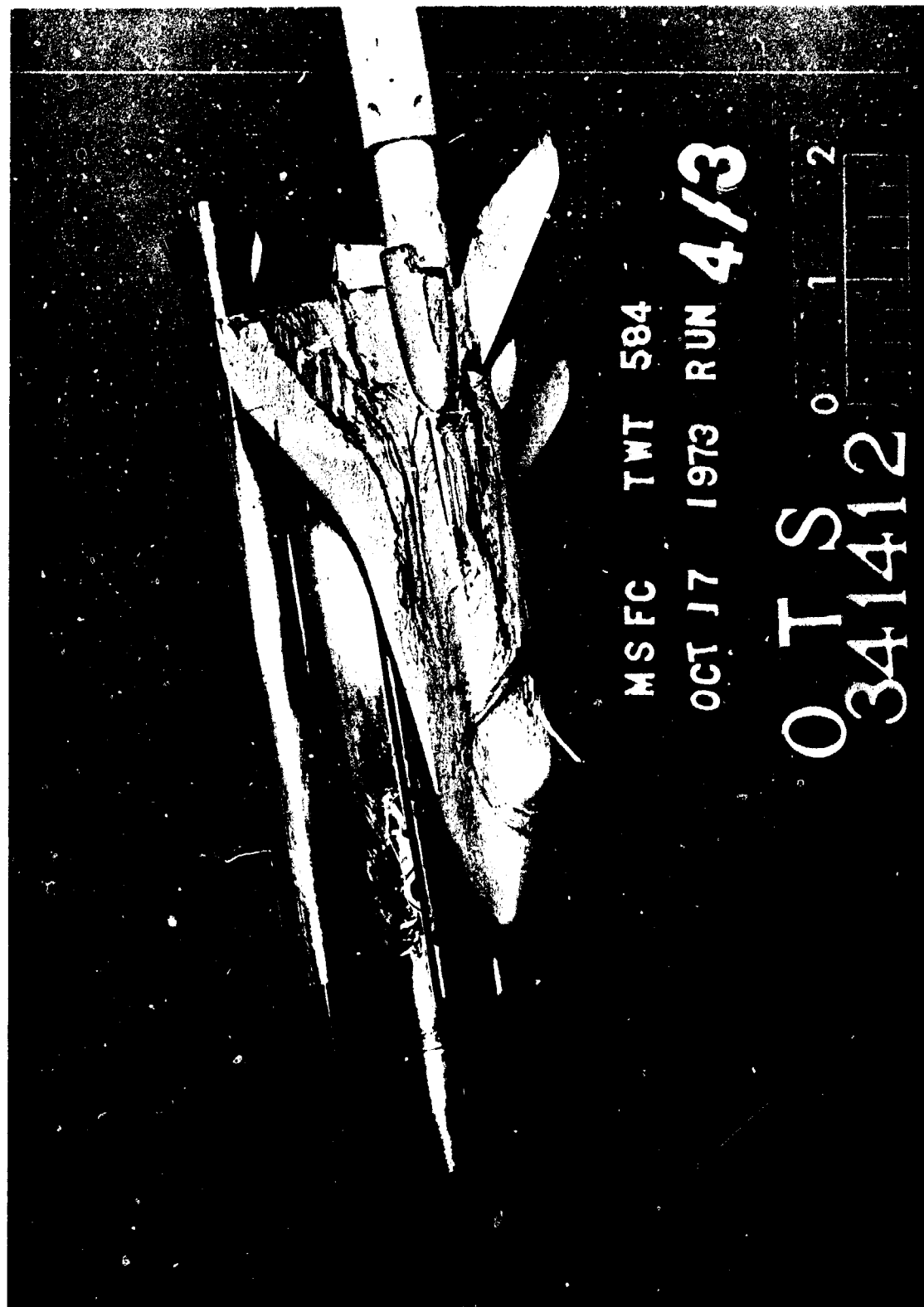


FIGURE 14. OIL FLOW PHOTOGRAPH OF INTEGRATED VEHICLE,  $\alpha = 10^\circ$ ,  $\beta = 3^\circ$ ,  $M = 4.96$ , RED AND YELLOW OIL PAINT (RIGHT OBLIQUE)

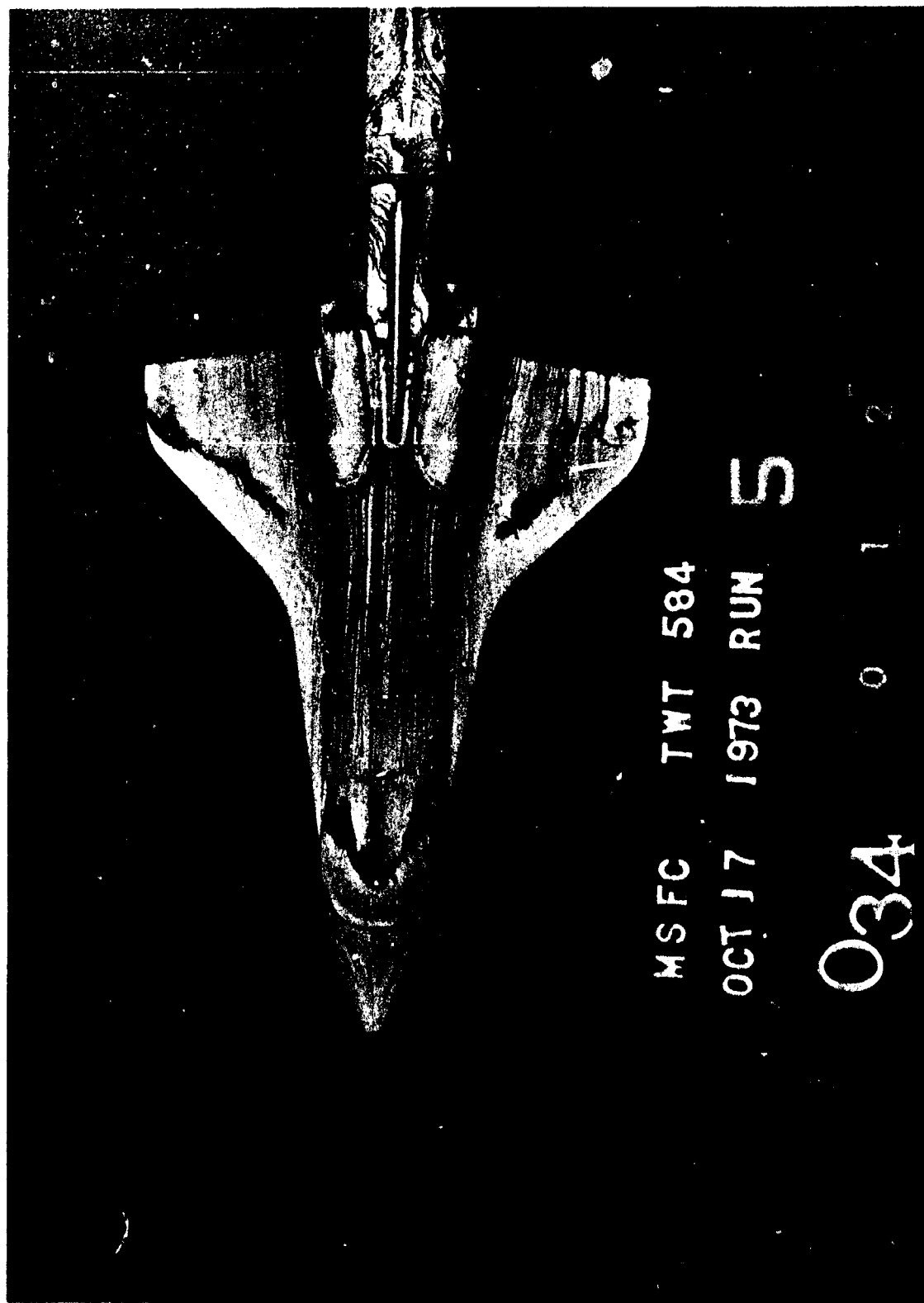
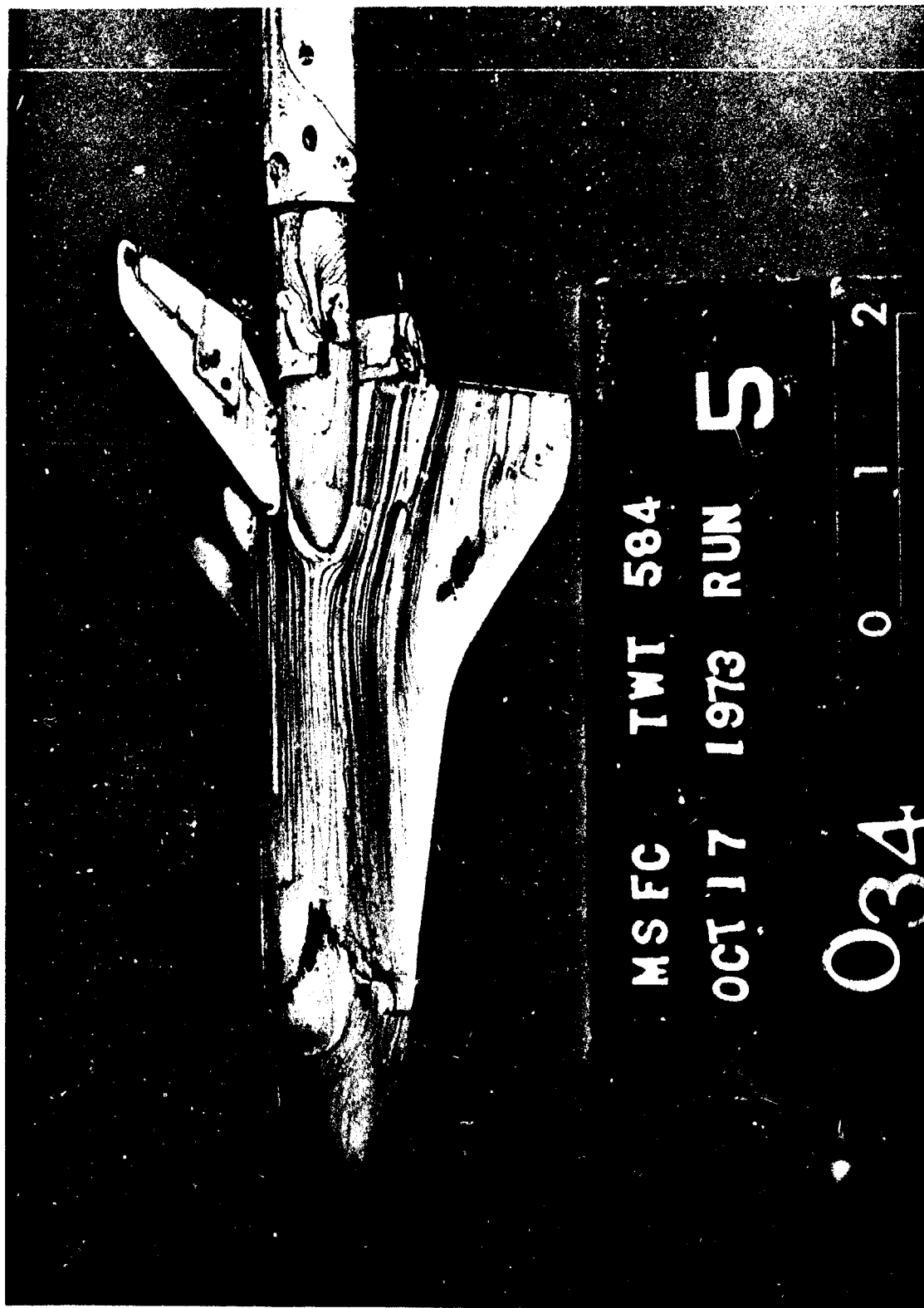


FIGURE 15. OIL FLOW PHOTOGRAPH OF ORBITER,  $\alpha = \beta = 0^\circ$ ,  $M = 0.9$ ,  
BLUE OIL PAINT (TOP VIEW)



MSFC TWT 584

OCT 17 1973 RUN 5

034 0 1 2

FIGURE 16. OIL FLOW PHOTOGRAPH ORBITER,  $\alpha = \beta = 0^\circ$ ,  $M = 0.9$ ,  
BLUE OIL PAINT (LEFT OBLIQUE)

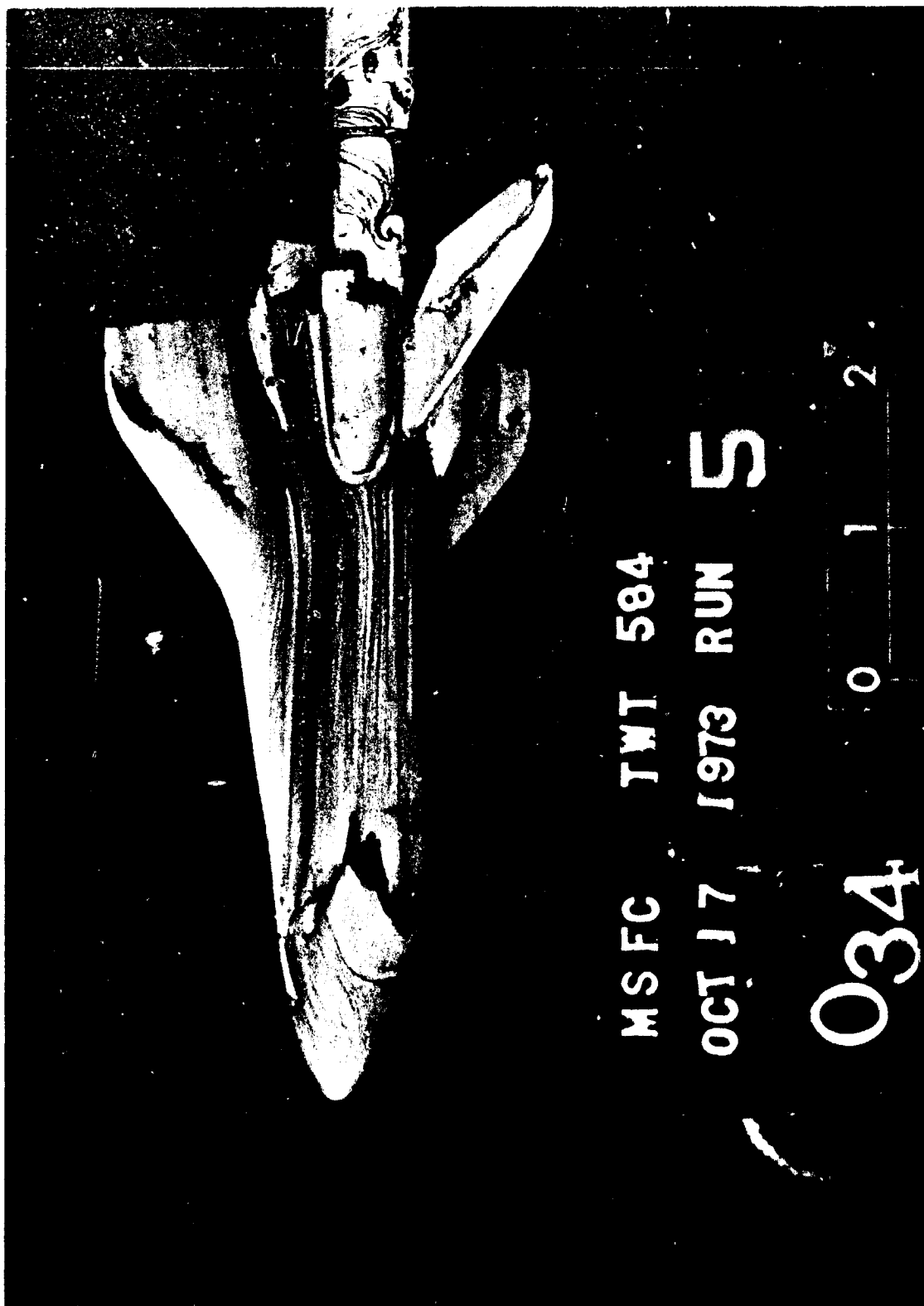
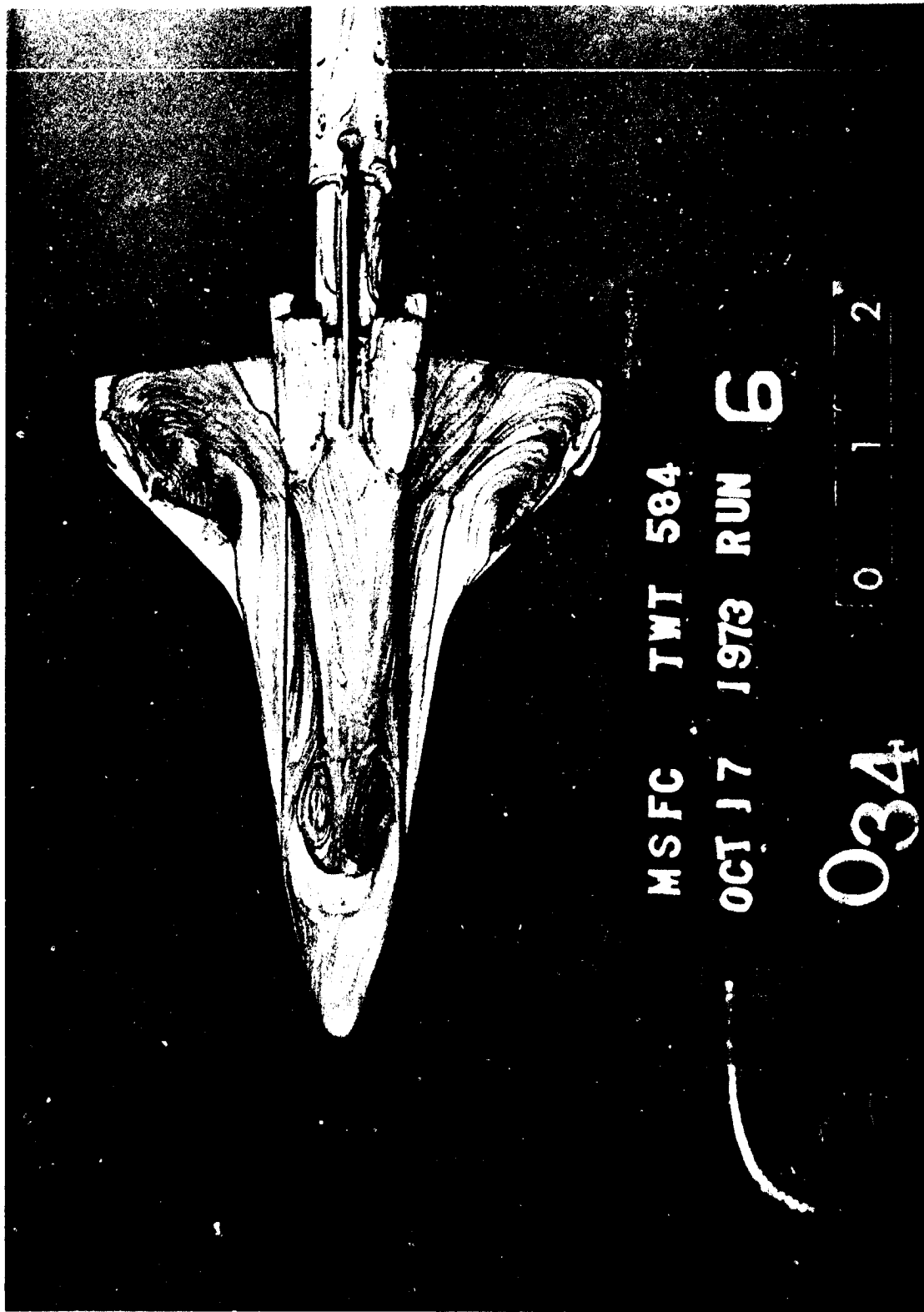


FIGURE 17. OIL FLOW PHOTOGRAPH OF ORBITER,  $\alpha = \beta = 0^\circ$ ,  $M = 0.9$ ,  
BLUE OIL PAINT (RIGHT OBLIQUE)



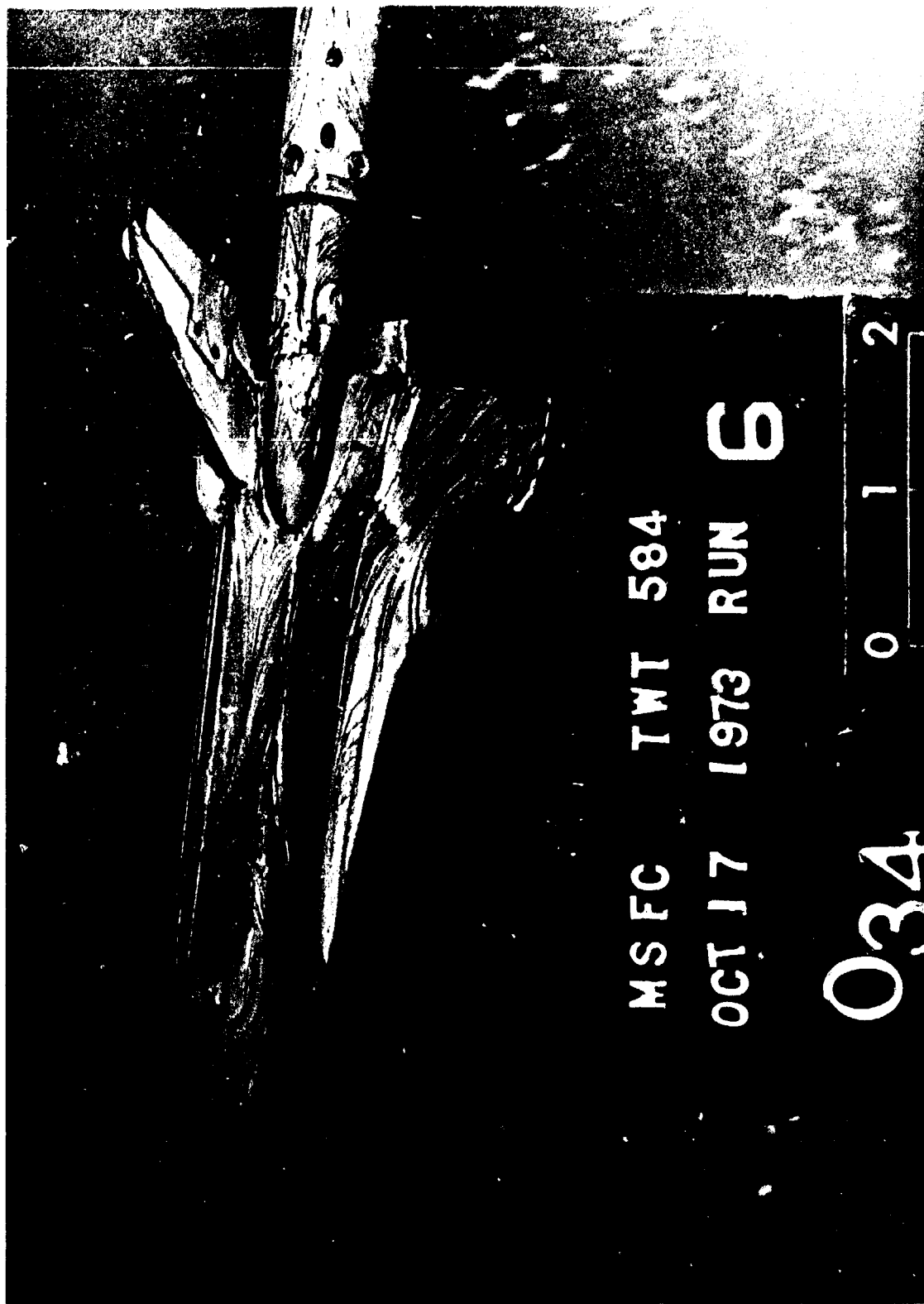
MSFC TWT 584

OCT 17 1973 RUN 6

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0	1	2
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FIGURE 18. OIL FLOW PHOTOGRAPH OF ORBITER,  $\alpha = 10^\circ$ ,  $\beta = 5^\circ$ ,  $M = 0.9$ ,  
BLUE OIL PAINT (TOP VIEW)



MSFC TWT 584

OCT 17 1973 RUN 6

034 0 1 2

FIGURE 19. OIL FLOW PHOTOGRAPH OF ORBITER,  $\alpha = 10^\circ$ ,  $\beta = 5^\circ$ ,  $M = 0.9$ ,  
BLUE OIL PAINT (LEFT OBLIQUE)

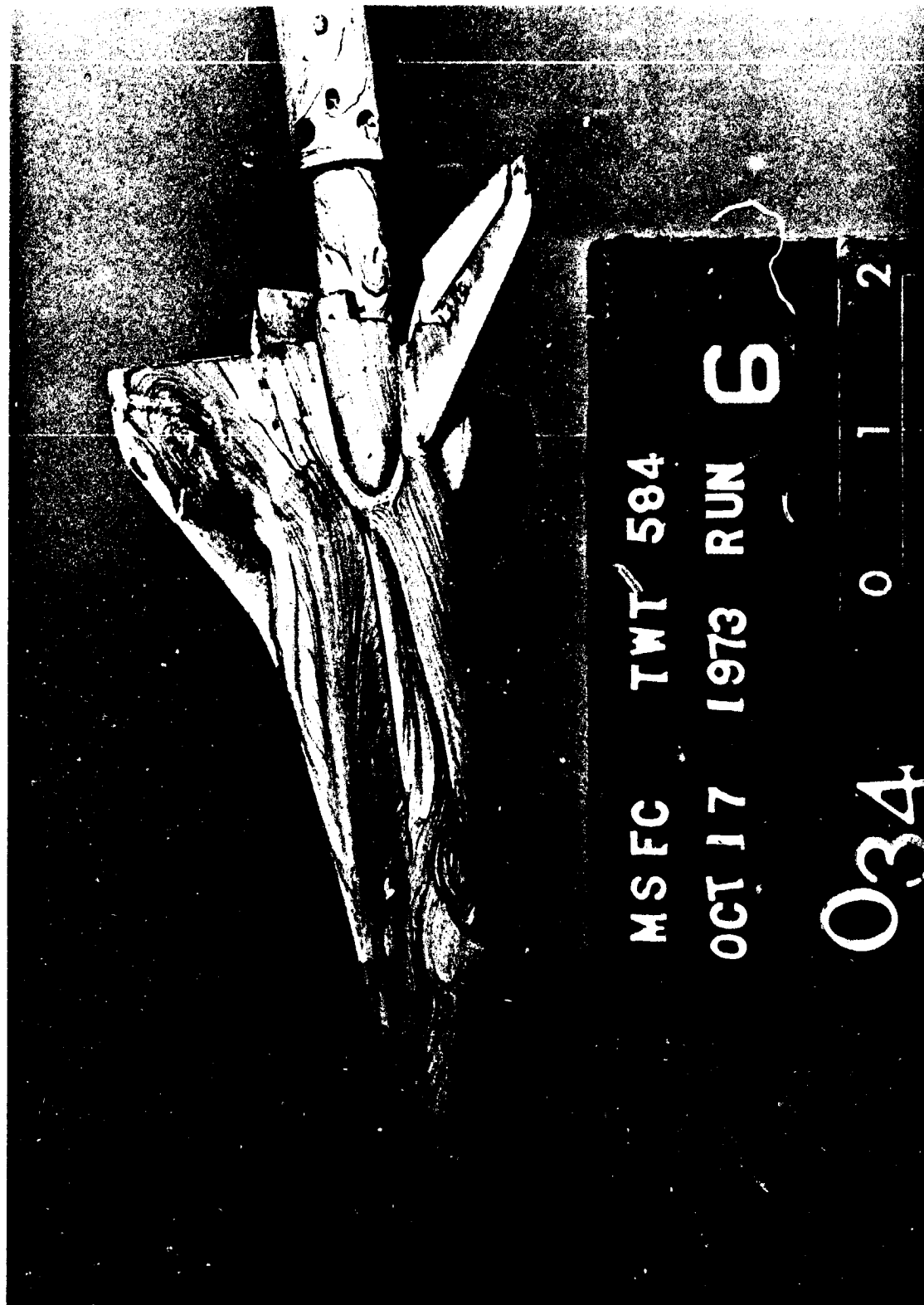
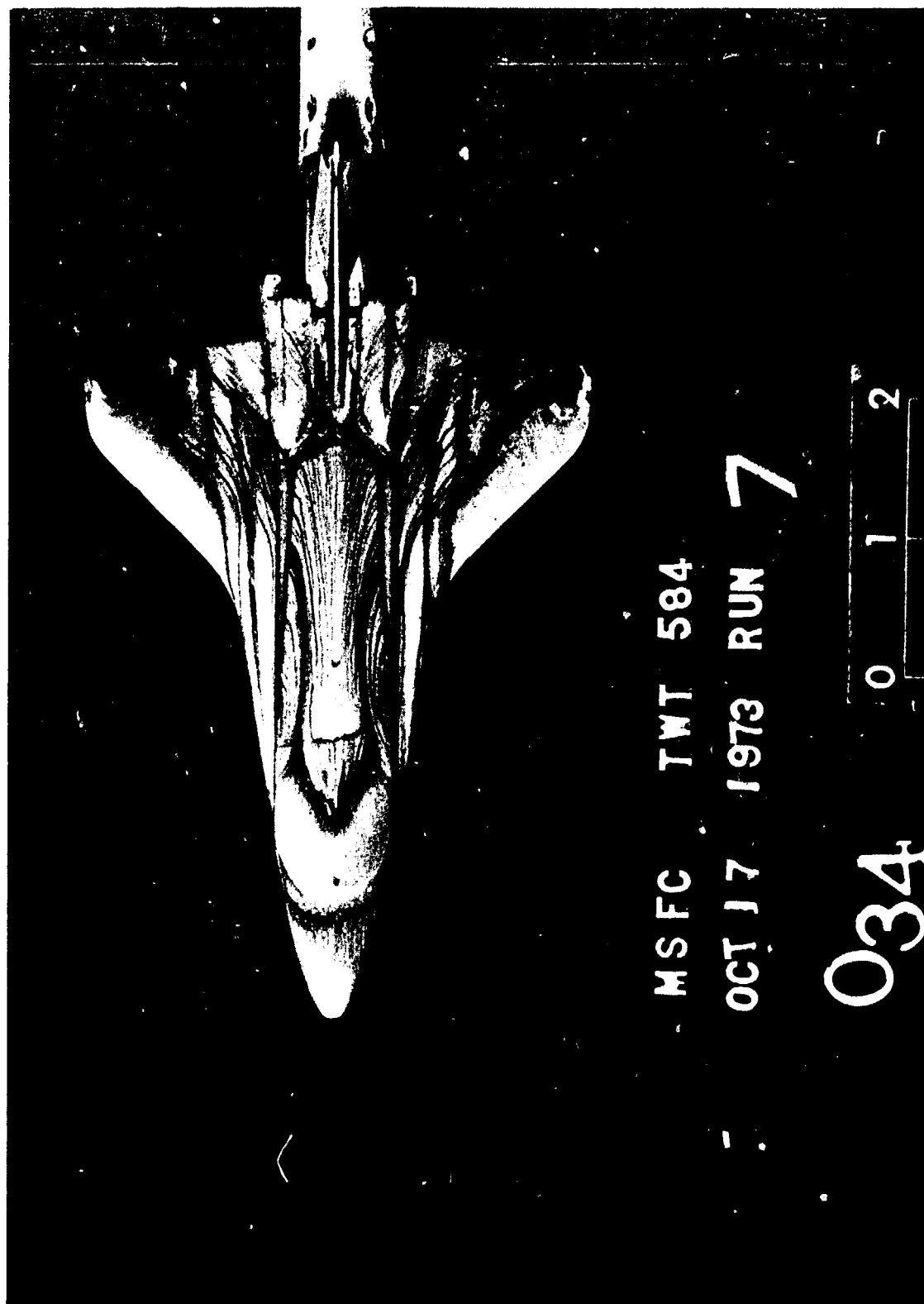


FIGURE 20. OIL FLOW PHOTOGRAPH OF ORBITER,  $\alpha = 10^\circ$ ,  $\beta = 5^\circ$ ,  $M = 0.9$ ,  
BLUE OIL PAINT (RIGHT OBLIQUE)





MSFC TWT 584

OCT 17 1973 RUN 7

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FIGURE 21. OIL FLOW PHOTOGRAPH OF ORBITER,  $\alpha = 10^\circ$ ,  $\beta = 5^\circ$ ,  $M = 1.96$ ,  
BLUE OIL PAINT (TOP VIEW)

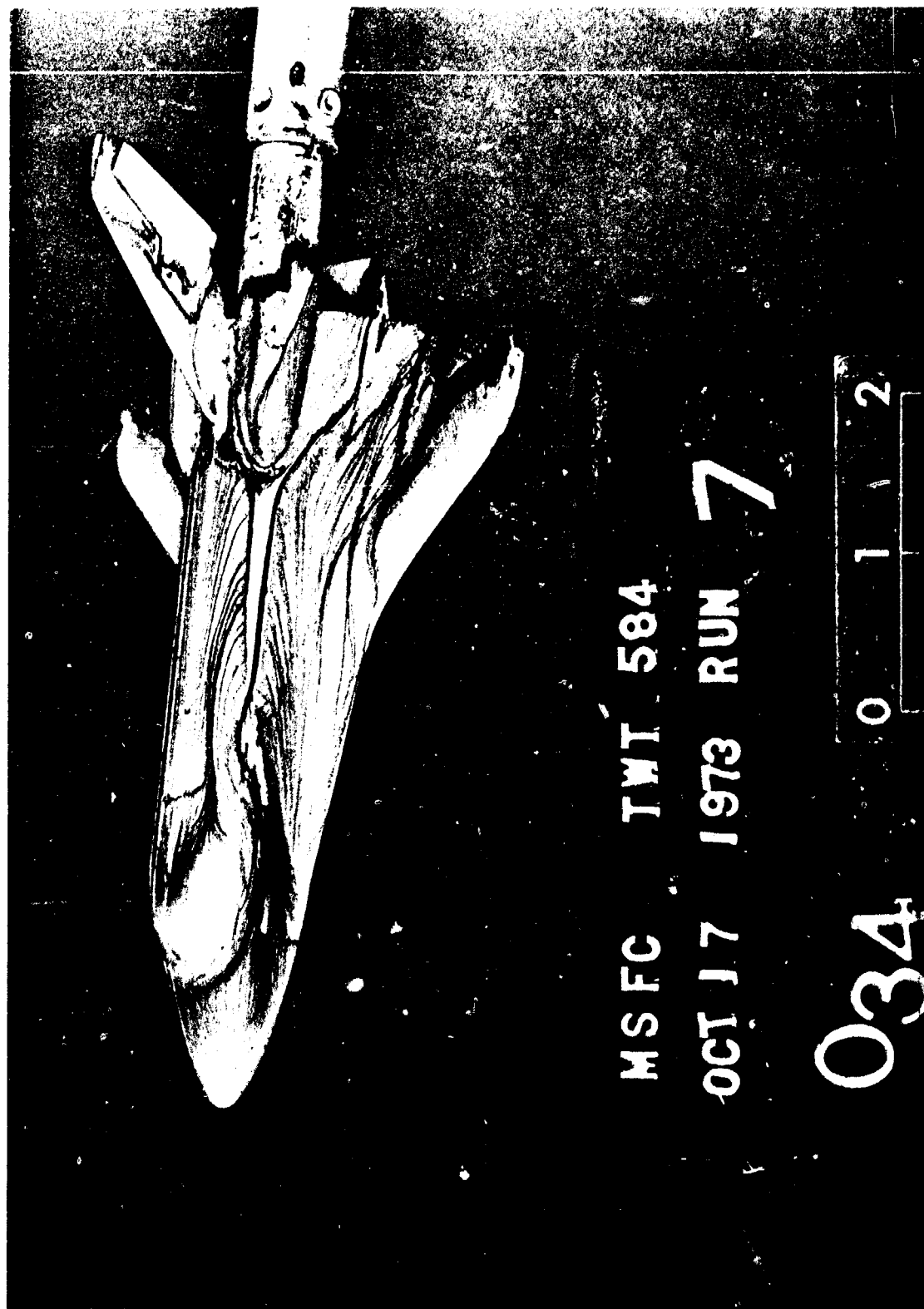


FIGURE 22. OIL FLOW PHOTOGRAPH OF ORBITER,  $\alpha = 10^\circ$ ,  $\beta = 0^\circ$ ,  $M = 1.96$ ,  
BLUE OIL PAINT (LEFT OBLIQUE)

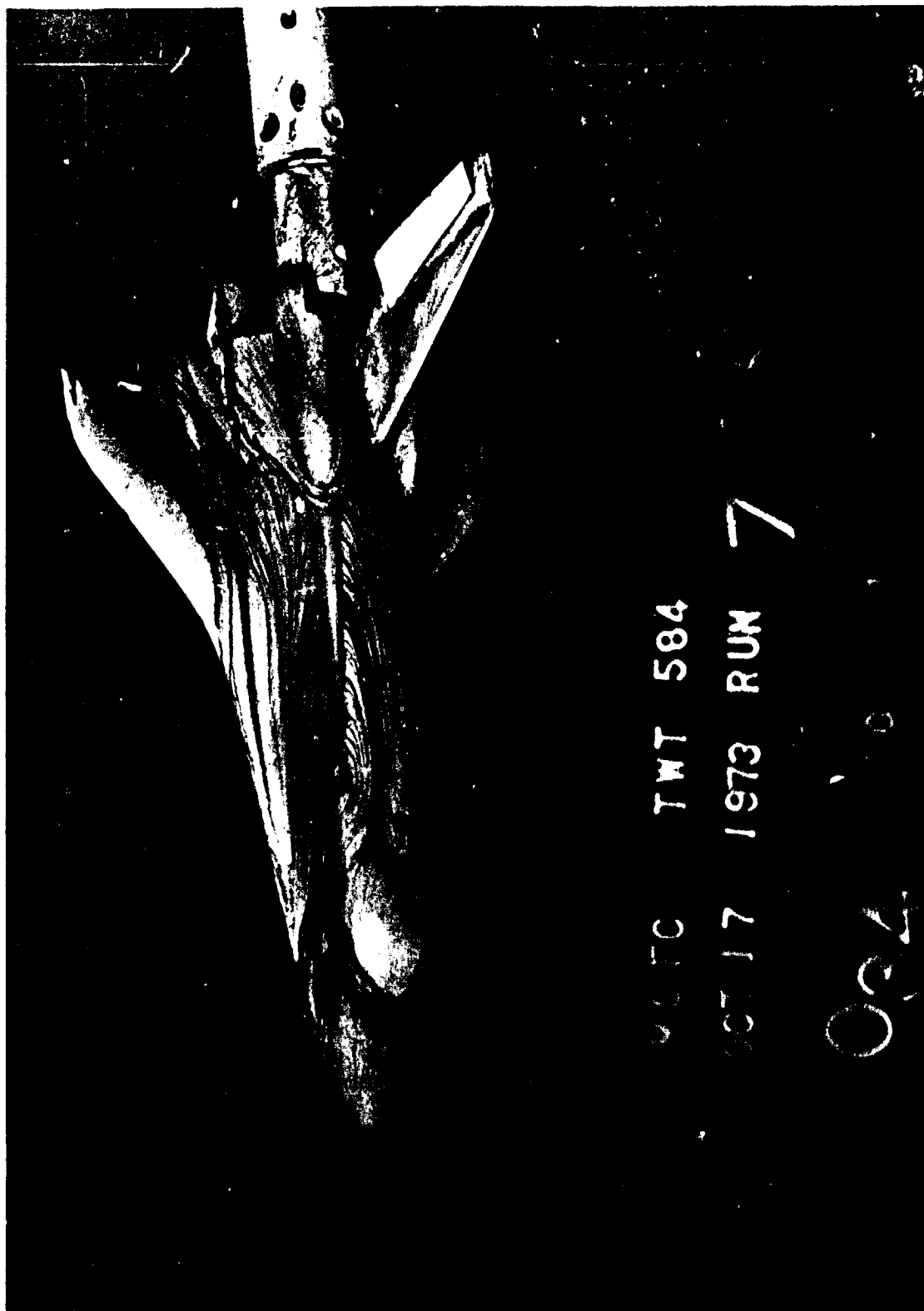
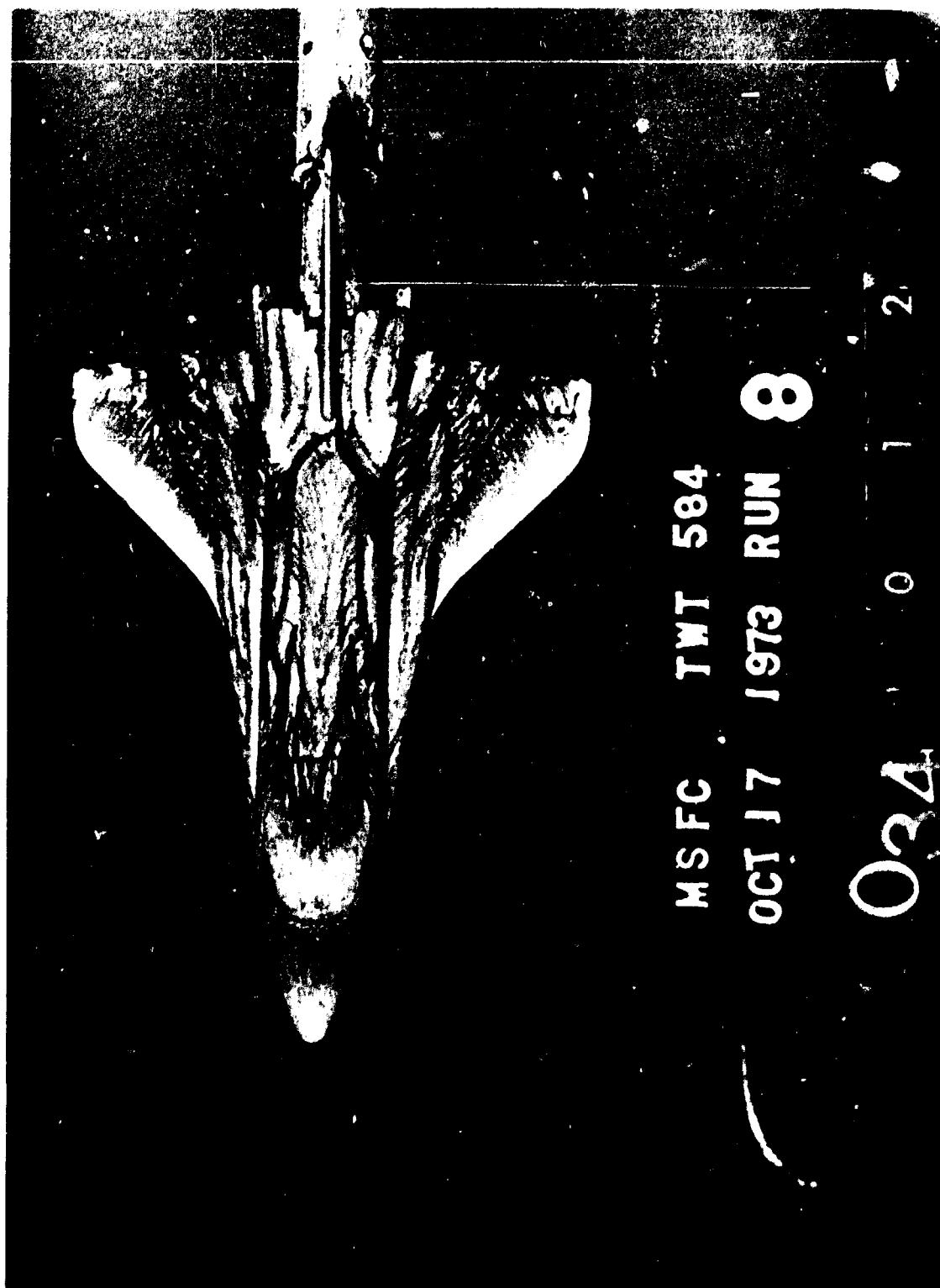


FIGURE 23. OIL FLOW PHOTOGRAPH OF ORBITER,  $\alpha = 10^\circ$ ,  $\beta = 0^\circ$ ,  $M = 1.96$ ,  
BLUE OIL PAINT (RIGHT OBLIQUE)



MSFC TWT 584

OCT 17 1973 RUN 8

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0

FIGURE 24. OIL FLOW PHOTOGRAPH OF ORBITER,  $\alpha = 10^\circ$ ,  $\beta = 0^\circ$ ,  $M = 2.99$ ,  
BLUE OIL PAINT (TOP VIEW)

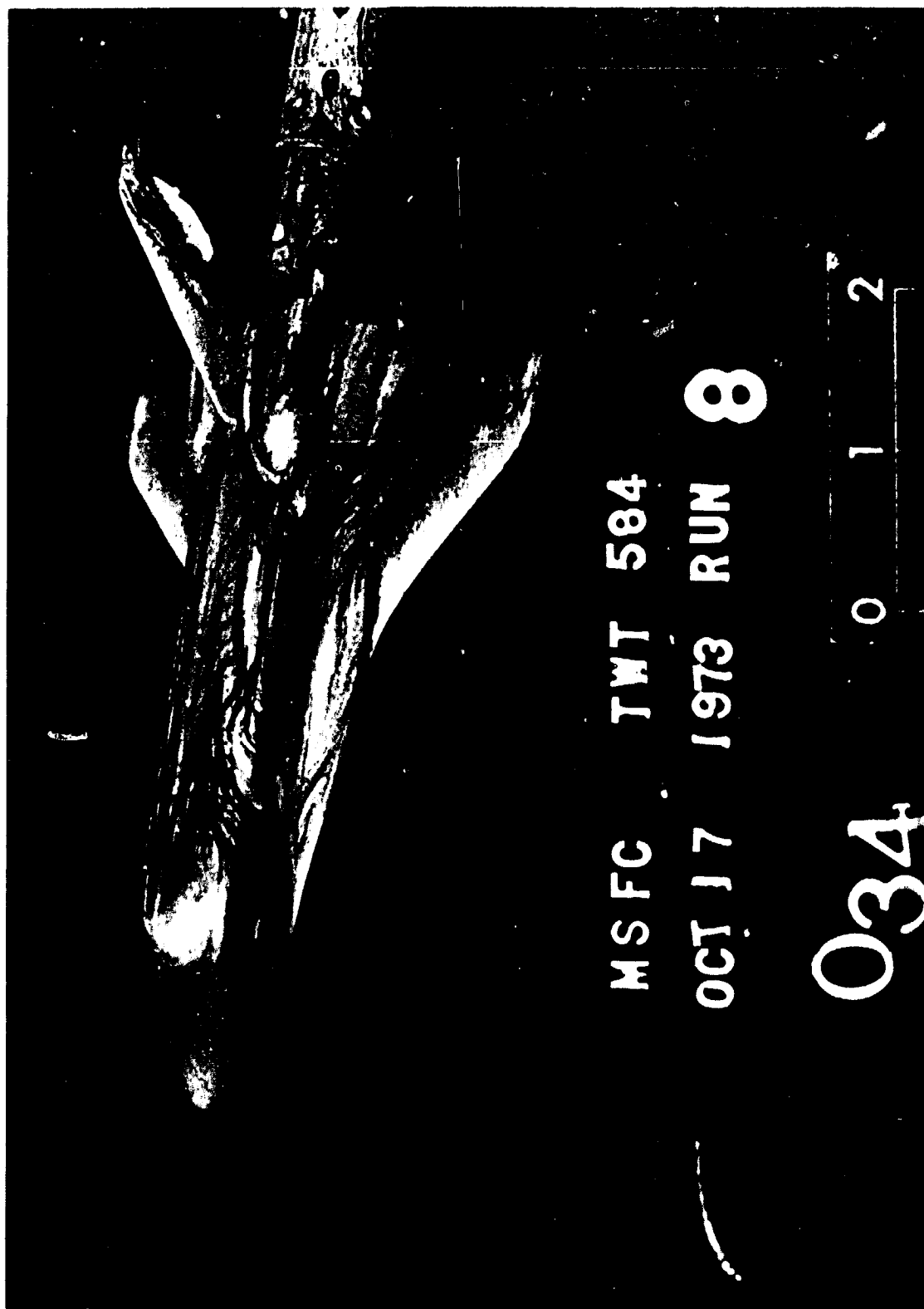


FIGURE 25. OIL FLOW PHOTOGRAPH OF ORBITER,  $\alpha = 10^\circ$ ,  $\beta = 0^\circ$ ,  $M = 2.99$ ,  
BLUE OIL PAINT (LEFT OBLIQUE)

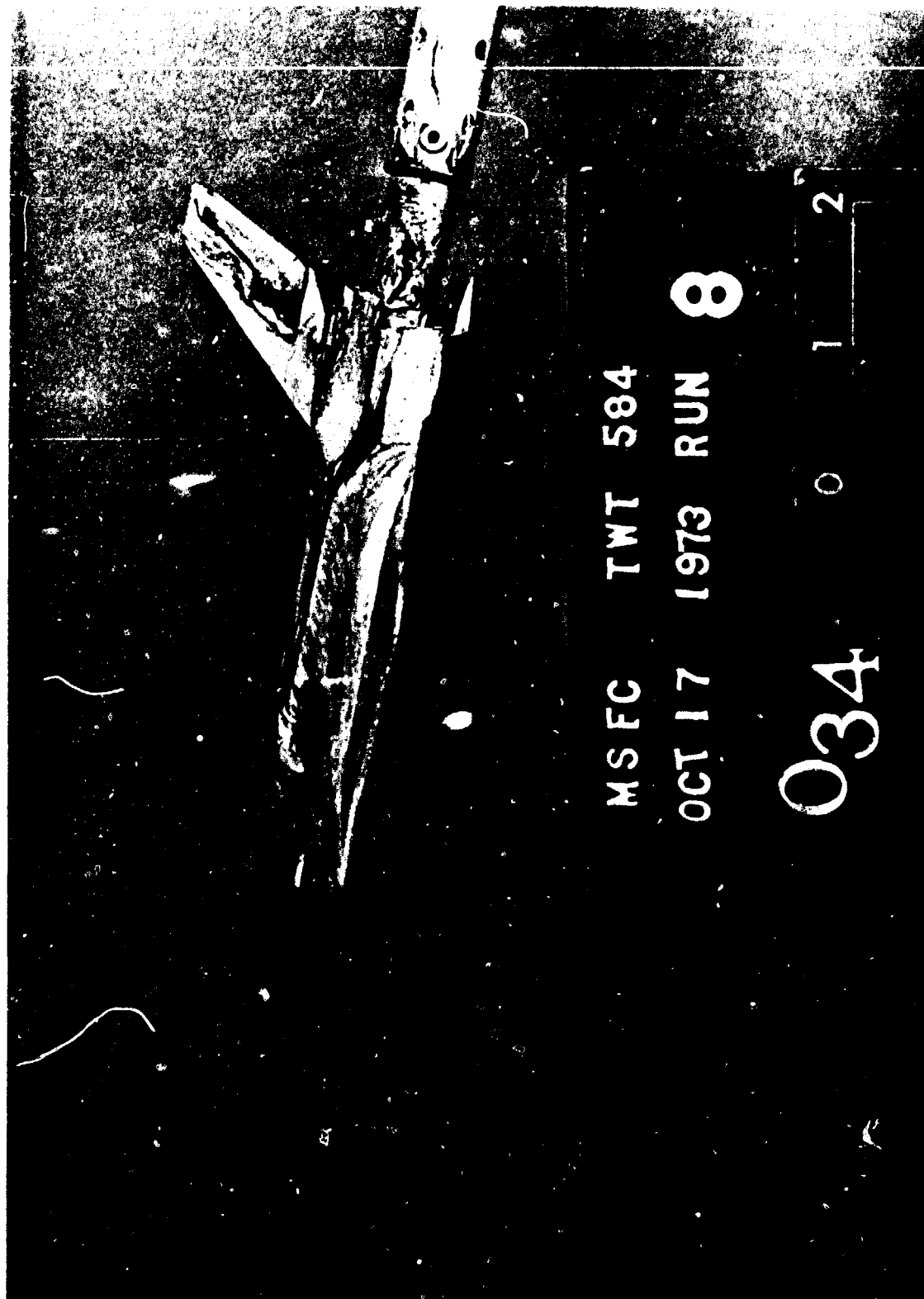


FIGURE 26. OIL FLOW PHOTOGRAPH OF ORBITER,  $\alpha = 10^\circ$ ,  $\beta = 0^\circ$ ,  $M = 2.99$ ,  
BLUE OIL PAINT (LEFT SIDE)

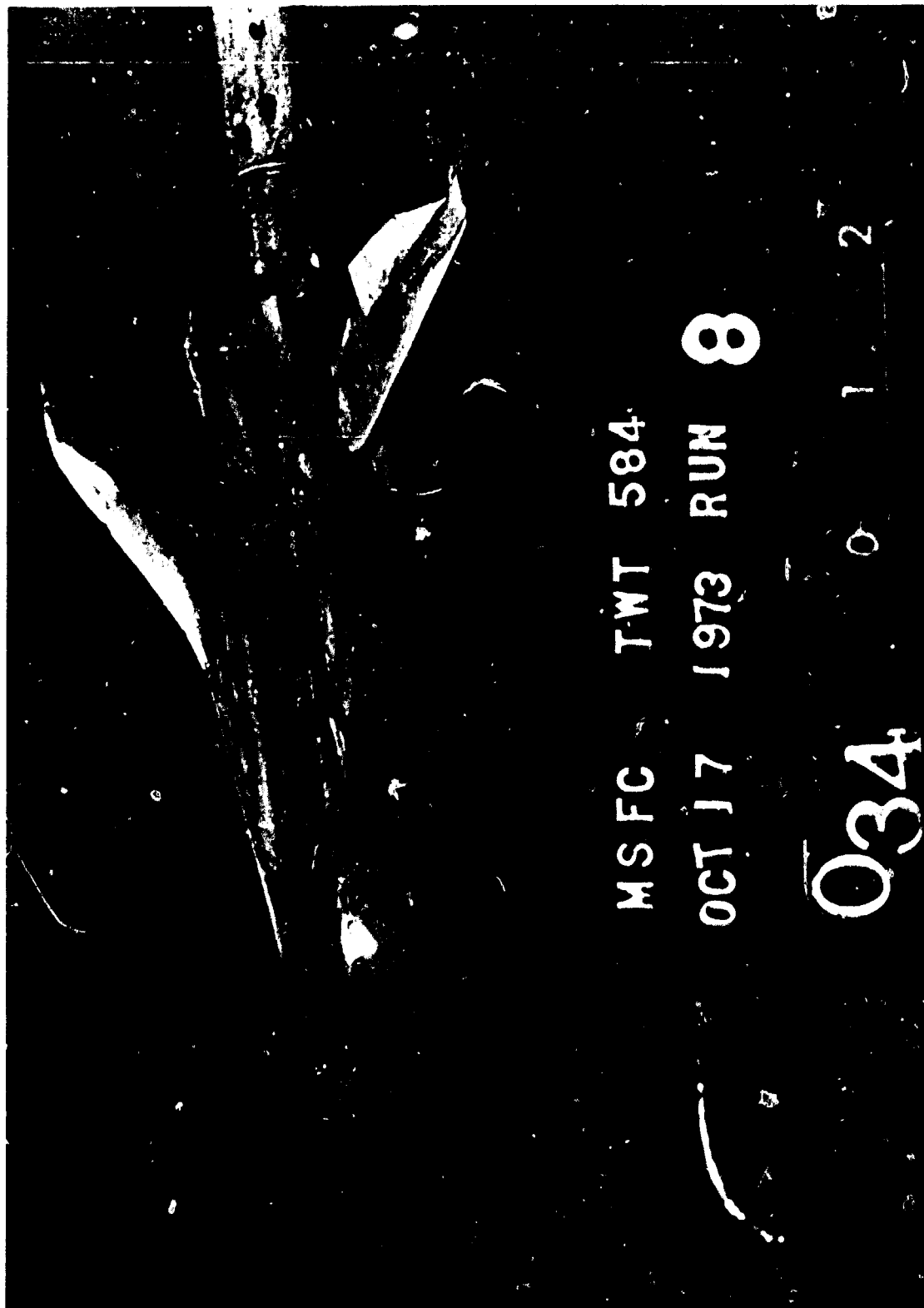


FIGURE 27. OIL FLOW PHOTOGRAPH OF ORBITER;  $\alpha = 10^\circ$ ,  $\beta = 0^\circ$ ,  $M = 2.99$ ,  
BLUE OIL PAINT (RIGHT OBLIQUE)



FIGURE 28. OIL FLOW PHOTOGRAPH OF ORBITER,  $\alpha = 10^\circ$ ,  $\beta = 0^\circ$ ,  $M = 4.96$ ,  
BLUE OIL PAINT (TOP VIEW)



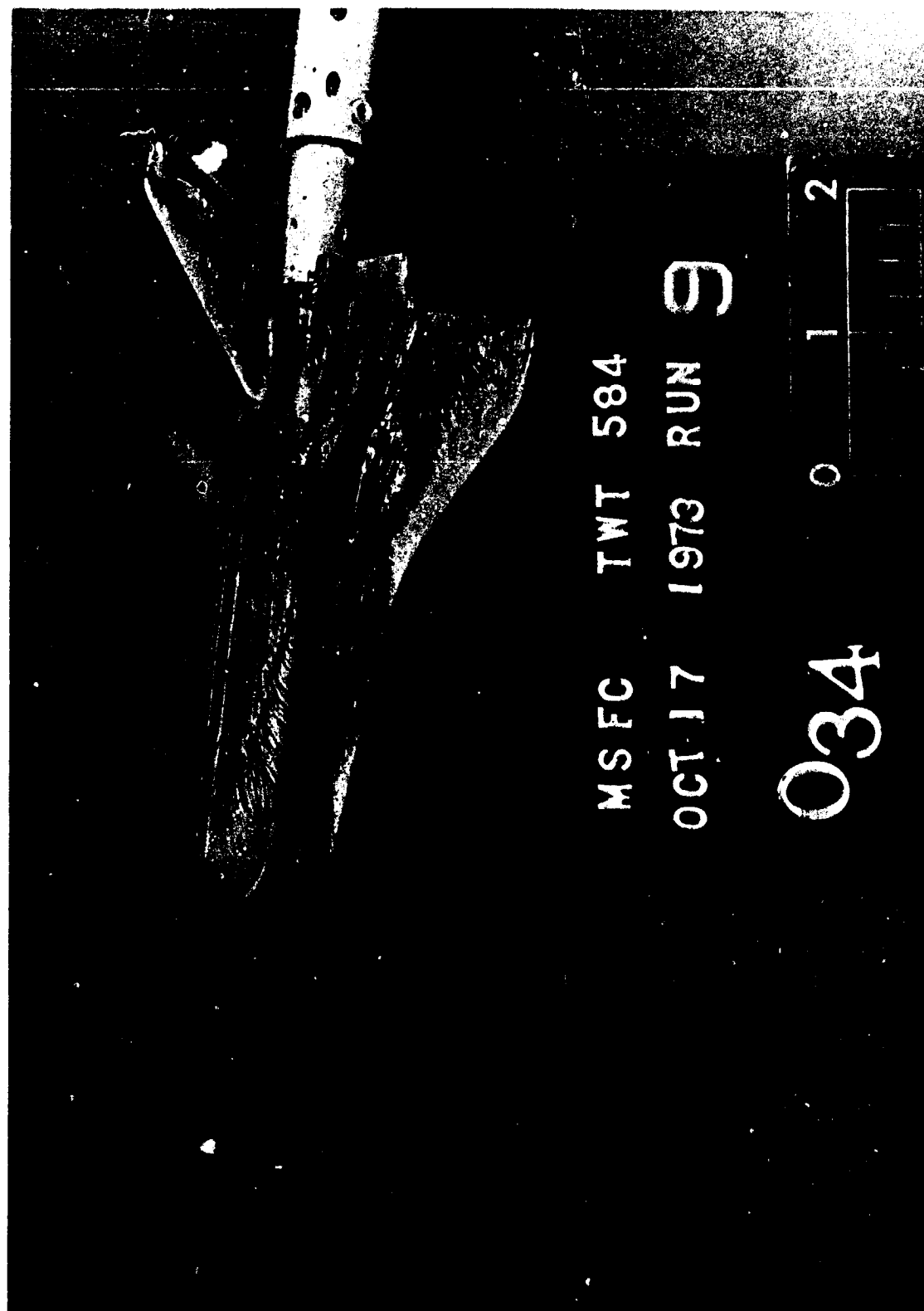


FIGURE 29. OIL FLOW PHOTOGRAPH OF ORBITER,  $\alpha = 10^\circ$ ,  $\beta = 0^\circ$ ,  $M = 4.96$ ,  
BLUE OIL PAINT (LEFT OBLIQUE)

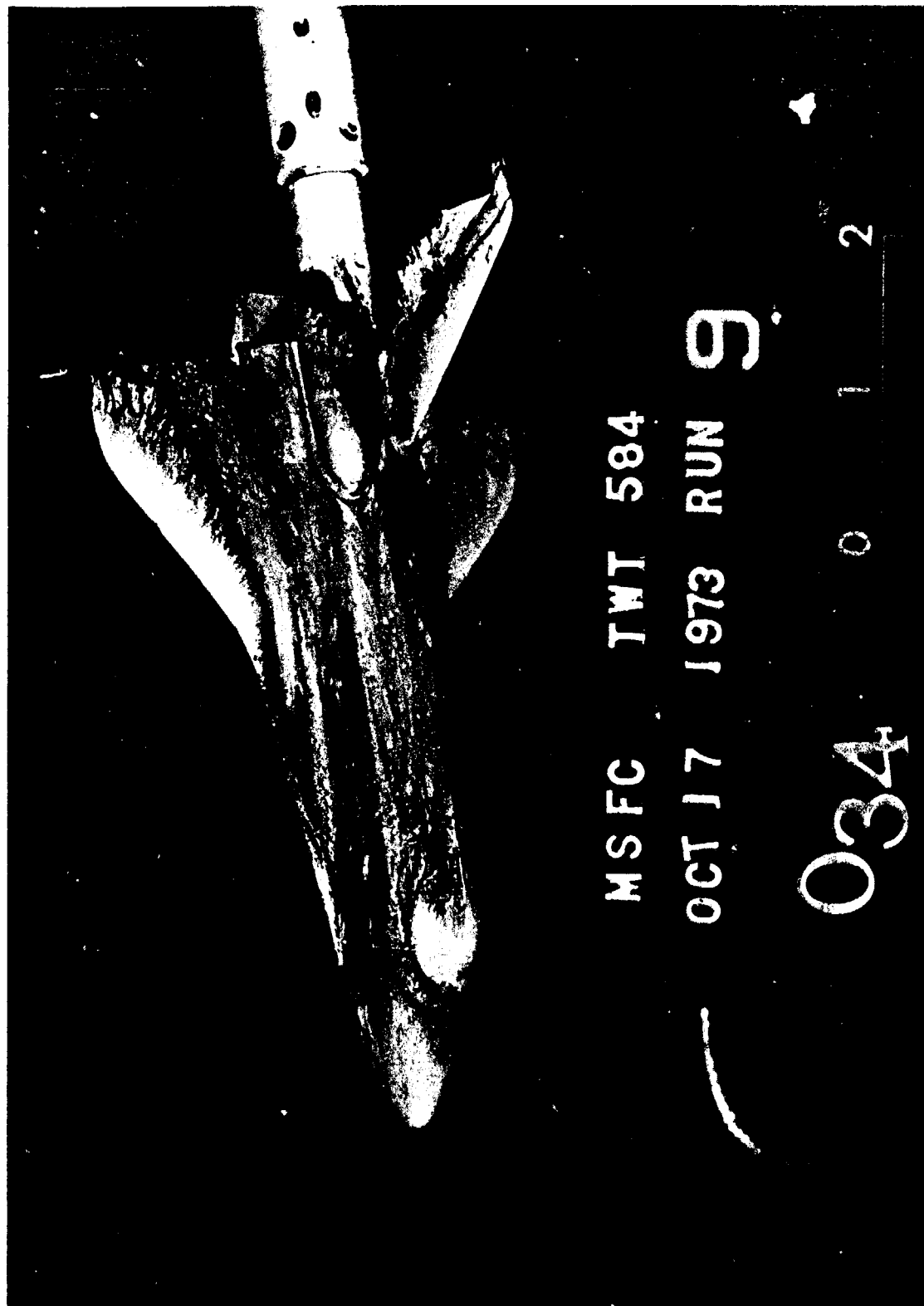


FIGURE 30. OIL FLOW PHOTOGRAPH OF ORBITER,  $\alpha = 10^\circ$ ,  $\beta = 0^\circ$ ,  $M = 4.96$ ,  
BLUE OIL PAINT (RIGHT OBLIQUE)

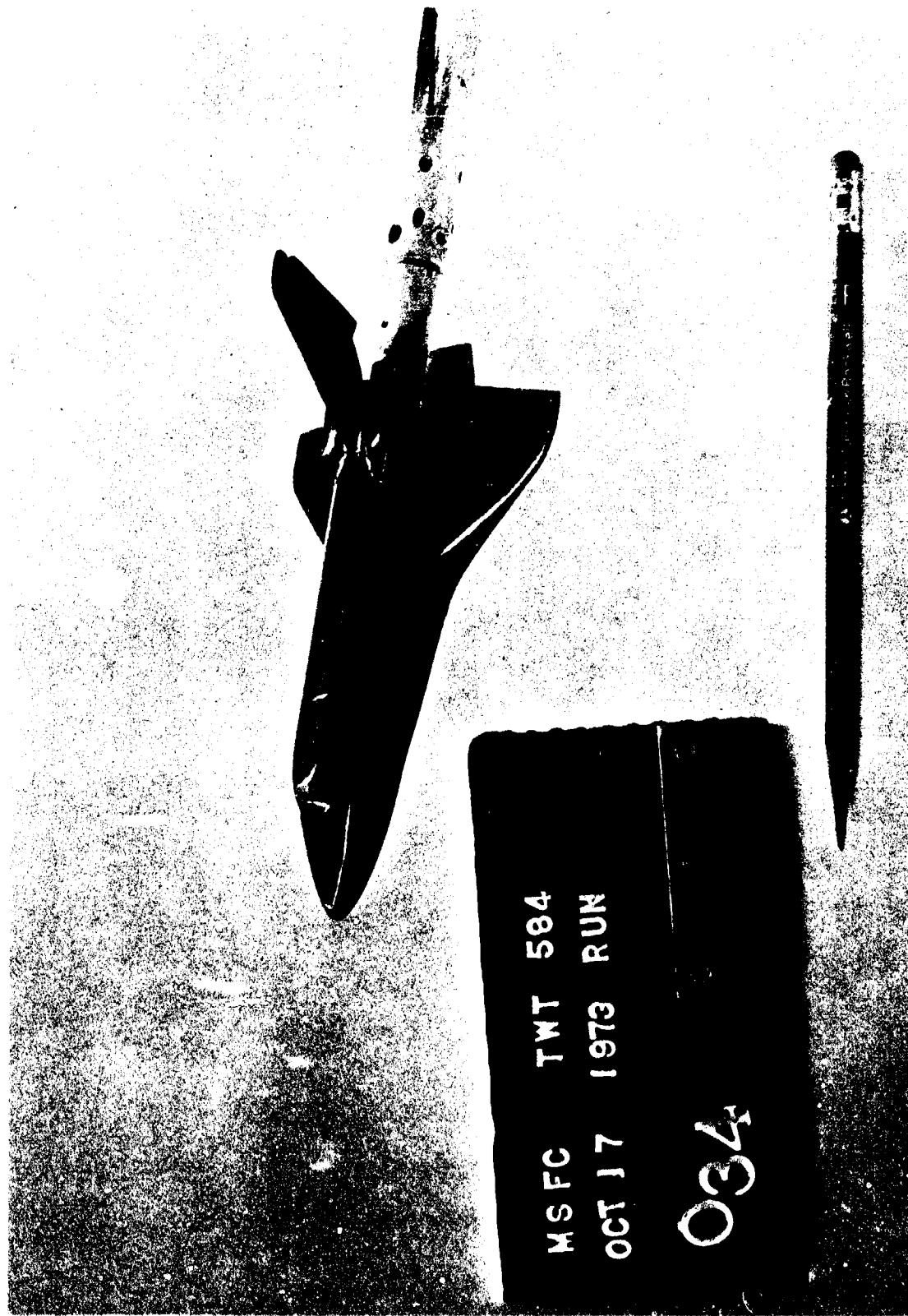
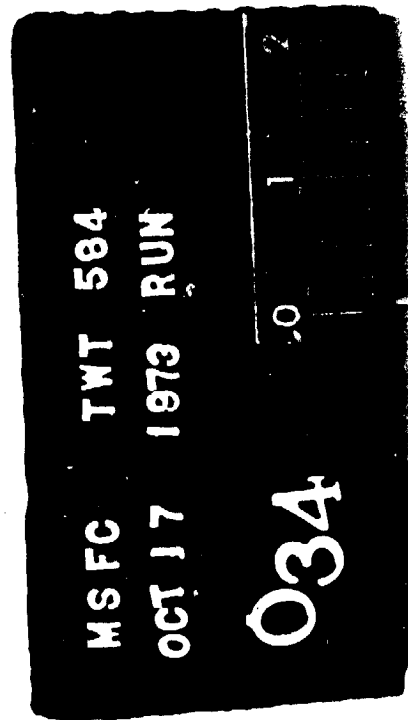
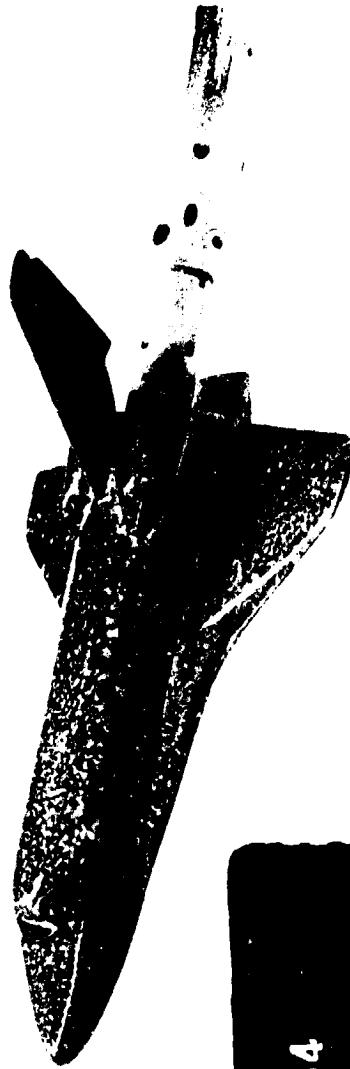


FIGURE 31. OIL FLOW PHOTOGRAPH OF MODEL PREPARATION: BLUE OIL PAINT BRUSHED ON AND WIPED DOWN



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FIGURE 32. OIL FLOW PHOTOGRAPH OF MODEL PREPARATION: APPEARANCE AFTER  
SPRAYING WITH MACHINE TOOL OIL